Laboratory Study of KCl-Polymer and Soltex Utilization in Preventing Swelling Shale in High Temperature

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Abstract. Mismanaging mud characteristics can create drilling issues and financial losses. Field drilling operations can avoid lost circulation (mud loss), stuck drill strings, uncontrolled blowouts, and caving shale by carefully selecting drilling mud that matches the formation characteristics of a well. The aim of this study is to develop a mud formulation that effectively mitigates shale-related issues while preserving the integrity of the physical properties of the formation. The use of appropriate polymer mud and shale stabilizers at 250 degrees Celcius, with KCl at 9 percent and Soltex at 2, 4, and 6 ppb, will help this study achieve its aim. In this study, clay swelling is measured with a linear swell meter. Test results will be shown as charts or graphs. We can see from the linear swell meter graph that using KCl polymer mud with Soltex at a concentration of 4 ppb is an effective way to reduce shale formation swelling by about 21.20 percent. This study proposes employing KCl polymer and Soltex to decrease shale swelling at high temperatures, which could have a positive effect on petroleum engineering. Precision in drilling mud composition and selection can improve drilling operations, which could reduce drilling expenses and financial losses.

1 Introduction

Drilling mud plays a crucial role in facilitating successful well drilling operations. Precise determination of the composition and selection of drilling mud is crucial for drilling a certain formation. This ensures smooth operation, determines drilling success, and prevents any potential complications. In addition, employing drilling mud that is suitable for the specific characteristics of the formation being drilled will result in an ideal rate of penetration and minimize the expenses associated with the drilling operation [1].

The American Petroleum Institute (API) defines drilling mud as a fluid used in drilling operations that serves multiple roles. Drilling mud is a significant component that affects

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the efficiency of drilling operations. The failure to control the physical qualities of mud leads to the malfunction of the sludge function, resulting in significant barriers to drilling operations and creating substantial financial losses. An approach to addressing the failure of the mud function is to investigate the physical and rheological features of the mud [2].

The primary physical characteristics of drilling mud that must be regulated in an effective oil and gas drilling operation are density, viscosity, gel strength, and filtration loss. Filtration loss refers to the loss of a liquid component from the drilling mud system into the formation that is being drilled. Conversely, the cohesive substance that adheres to the inner surface of the drill hole is referred to as mudcake. The filtrate's impact is to induce formation damage or swelling and diminish the borehole diameter as a result of the mudcake's presence [1].

The challenges posed by shale in petroleum operations are not new. In the early 1950s, numerous experts in soil mechanics focused their attention on the phenomenon of clay swelling. This phenomenon is crucial for ensuring the stability of wellbores during drilling, particularly in formations composed of water-sensitive shale and clay. The rocks in these formations have the capacity to absorb the drilling fluid, resulting in their destabilization and perhaps causing the collapse of the wellbore. The literature has examined the expansion of clays and the resulting issues [3, 4, 5,6].

Shale constitutes 75% of the drilled deposits and is the primary cause of wellbore instability. Regrettably, shale exhibits sensitivity to water-based drilling fluids. Consequently, oil-based drilling fluids have been the preferred option for difficult shale formations for an extended period of time [7, 8, 9, 10]. Over the course of several decades, numerous additives have been developed and implemented to enhance the stability of shale [11]. Since the 1960s, KCl-polymer mud has been utilized for the purpose of drilling several shale formations [12]. Drilling mud plays a crucial role in drilling operations. The parameters of the drilling fluid play a crucial role in determining the optimal drilling operation. Hence, enhancing the characteristics of these fluids is crucial to aligning them with the conditions in the field [13]. The formulation of the drilling mud must be tailored to the specific pressure and temperature conditions of the formation being drilled. Furthermore, it is crucial to take into account the characteristics of the mud, as the layers or formations that the mud penetrates may differ or undergo alterations. As a result, it is necessary to modify the mud's characteristics by using appropriate additives.

The utilization of KCl-polymer mud is extensive in drilling operations conducted in regions with active shale formations. The mud serves as a stabilizer for boreholes and reduces the dispersion of cuttings, allowing this polymer to effectively transport drilling powder during borehole cleaning [14, 10].

A polymer is an ingredient employed to modify the viscosity of the mud. The utilization of polymer mud is anticipated to mitigate common drilling issues and decrease drilling expenses. The mud system employed in drilling operations nowadays is Potassium Chloride polymer (KCl polymer), which is the most commonly utilized polymer mud. KCl-polymer muds are specifically formulated to reduce borehole stability issues [15]. Borehole instability can occur due to either excessive overburden pressure or the hydration of formation clays [16]. Incorporating Potassium Chloride into the mud will introduce potassium ions, which will aid in the stabilization of the reactive clay. Thus, the occurrence of clay swelling can be reduced. A polymer will encapsulate and extract the clay rocks produced during drilling, and solid control equipment will mechanically sort them [14]. To reduce the swelling and hydration of clay, it is necessary to use relatively high concentrations of KCl, typically ranging from 2% to 37% [17].

The objective of this study is to create a mud composition that may efficiently mitigate shale-related problems while maintaining the intact physical characteristics of the formation. To do this, we will employ polymer mud and shale stabilizer additives, namely KCl at a concentration of 9% and Soltex at concentrations of 2 ppb, 4 ppb, and 6 ppb. The shale development will be assessed using a Linear Swell Meter. The desired outcome is to employ the most effective shale stabilizer chemicals while drilling in water-reactive shale formations to tackle the problem of shale swelling.

2 Method

In order to achieve the research objective, appropriate polymer mud and shale stabilizers at 250 °F—KCl at 9% and Soltex at 2, 4, and 6 ppb were used. Shale stabilizer, which in this research uses KCl and Soltex, is a substance used to prevent swelling in shale formations, ensuring that the shale remains intact and does not collapse into the drilling hole. The addition of KCl to water will result in the dissociation of the compound into K+ and Cl- ions. When stabilizing the shale material, potassium ions (K+) will displace sodium ions (Na+) from their positions. In shale, potassium ions (K+) exhibit a significantly higher affinity for binding with clay compared to sodium ions (Na+), resulting in stronger interactions between clay and water. Consequently, this leads to a decrease in the resistance to the removal of clay particles from water, indicating stronger connections between the clay and ions.

Soltex is an additive that chemically interacts with shale to inhibit or halt its swelling and reduce the negative impact on the formation's productivity. It also creates a thin and durable layer of mud cake and effectively manages water loss, even at high temperatures. In this study, clay swelling is measured with a linear swell meter. Test results will be shown as charts or graphs.

For more details, the experimental procedures in this research are: (A) Preparation the condition of drilling-mud before and after the Roller Oven 250 in order to determine the drilling-mud effectiveness that would withstand the physical properties at the high temperature conditions of 250 ° F; (B) Divide the drilling-mud into five formulations, i.e. Formulation I : Polymer added into drilling-mud, Formulation II : KCL Polymer added into drilling-mud, Formulation III : KCl Polymer and Soltex with 2 ppb added into drilling-mud, Formulation IV : KCl Polymer and Soltex with 4 ppb added into drilling-mud, and the last is Formulation V : KCl Polymer and Soltex with 6 ppb added into drilling-mud; (C) Measurement the physical properties of each drilling-mud formulation; and (D) Shale development test using linear-swell-meter.

3 Results and discussion

As the research objective was to assess the mud's ability to withstand the physical properties under high temperature conditions, specifically at 250°F, the drilling mud was divided into five formulations, as follows: *Formulation I:* Polymer added into drilling mud; *Formulation II:* KCL Polymer added into drilling mud; *Formulation III:* KCl Polymer and Soltex with 2 ppb added into drilling mud; *Formulation IV:* KCl Polymer and Soltex with 4 ppb added into drilling mud; and the last is *Formulation V:* KCl Polymer and Soltex with 6 ppb added into drilling mud. Each mud type was formulated after subjecting the roller oven to a temperature of 250°F. Because the objective was to assess the mud's ability to withstand the physical properties under high temperature conditions, specifically at 250°F. For more details are written in the following **Table 1.**

Table 1. Drilling-mud Data After Roller Oven 250°F

No	Mud Properties	Requirement		Result After Roller Oven 250°F				
				Polymer	KCl Polymer	KCl Polymer + Soltex 2 ppb	KCl Polymer + Soltex 4 ppb	KCl Polymer + Soltex 6 ppb
1	Mud Weight	gr/ml	1.09 - 1.16	1.09	1.11	1.11	1.09	1.11
2	READING @120ºF : 600	rpm		46	52	40	55	60
3	READING @120ºF : 300	rpm	-	31	34	30	36	40
4	READING @120ºF : 200	rpm	-	24	27	24	28	29
5	READING @120ºF : 100	rpm	-	16	18	17	19	19
6	READING @120ºF : 6	rpm	-	5	6	7	6	6
7	READING @120ºF : 3	rpm	-	3	5	6	5	5
8	Plastic Viscosity	cp	≤ 20	15	18	10	19	20
9	Yield Point	$lb/100ft^2$	12 - 21	16	16	20	17	20
10	Gel Strength 10"	$lb/100ft^2$	3 - 8	3	4	6	5	5
11	Gel Strength 10'	$lb/100ft^2$	6 - 14	4	7	8	10	10
12	pH	-C16	9.0 - 9.5	9.1	9.05	9.13	9.43	9.4
13	API Filtrate	ml/30 min	< 6.0	5.8	5.8	5.5	5.8	5.4
14	API Mud cake	mm	< 1.5	0.98	0.68	0.58	0.73	0.77
15	K^+	mg/l	$\geq$ 33000	36216	36216	36216	36216	36216
16	HTHP Filtrate (250^0F)	ml/30 min	≤ 20	19	17.4	18	19	19.2
17	HTHP Mud cake (250^0F)	mm	≤ 2	1.78	1.98	1.97	1.88	1.98

Table 1 is the data on the results of each of the five drilling mud formulations. All the drilling mud formulation was done after subjecting the roller oven to a temperature of 250°F.

3.1 Mud weight measurement

In mud weight measurements, the Formulation Drilling-Mud I yields 1.09 gr/ml, the Formulation Drilling-Mud II yields 1.11 gr/ml, the Formulation Drilling-Mud III yields 1.11 gr/ml, the Formulation Drilling-Mud IV yields 1.09 gr/ml, and the Formulation Drilling-Mud V yields 1.11 gr/ml. Meanwhile, the required specification (Rheology Standard for Drilling Mud at depths of 6000–9000 ft) is 1.09–1.16 gr/mL [18][19]. From the test results, it can be seen that all the results are within the specification standard that can be categorized as good mud.

3.2 Plastic viscosity measurement

In Plastic Viscosity (PV) measurements, the Formulation Drilling-Mud I yields 15 cp, the Formulation Drilling-Mud II yields 18 cp, the Formulation Drilling-Mud III yields 10 cp, the Formulation Drilling-Mud IV yields 19 cp, and the Formulation Drilling-Mud V yields 20 cp. Meanwhile, the specification must be met (< 20 cp) [18][19]. In these results, all the mud formulations have met the specifications of the drilling-mud standard.

3.3 Yield point measurement

For Yield Point (YP) test results, the Formulation Drilling-Mud I yields 16 lbs/100 ft^2, the Formulation Drilling-Mud II yields 16 lbs/100 ft^2, the Formulation Drilling-Mud III yields 20 lbs/100 ft^2, the Formulation Drilling-Mud IV yields 17 lbs/100 ft^2, and the Formulation Drilling-Mud V yields 20 lbs/100 ft^2. Meanwhile, the specification that must be met is 12–21 lbs/100 ft^2 [18][19]. In these results, all the mud formulations have met the specifications of the drilling-mud standard.

3.4 Gel strength measurement

In Gel Strength measurements of 10 seconds, the required drilling-mud specification is 3–8 lbs/100 ft^2 [18][19]. The Formulation Drilling-Mud I yields 3 lbs/100 ft^2, the Formulation Drilling-Mud II yields 4 lbs/100 ft^2, the Formulation Drilling-Mud III yields 6 lbs/100 ft^2, the Formulation Drilling-Mud IV yields 5 lbs/100 ft^2, and the Formulation Drilling-Mud V yields 5 lbs/100 ft^2.

At Gel Strength measurement of 10 minutes, the required drilling-mud specification is 6–14 lbs/100 ft^2 [18][19]. The Formulation Drilling-Mud I yields 6 lbs/100 ft^2, the Formulation Drilling-Mud II yields 7 lbs/100 ft^2, the Formulation Drilling-Mud III yields 8 lbs/100 ft^2, the Formulation Drilling-Mud IV yields 10 lbs/100 ft^2, and the Formulation Drilling-Mud V yields 10 lbs/100 ft^2. In these results, all formulations have met the specifications of the drilling-mud standard.

3.5 pH measurement

In pH measurement, the Formulation Drilling-Mud I yields 9.10, the Formulation Drilling-Mud II yields 9.05, the Formulation Drilling-Mud III yields 9.13, the Formulation Drilling-Mud IV yields 9.43, and the Formulation Drilling-Mud V yields 9.4. Meanwhile, the required specification was 9.0–9.5 [18][19]. In these results, all formulations have met the specifications of the drilling-mud standard.

3.6 Api filtrate measurement

For API Filtrate, the Formulation Drilling-Mud I yields 5.8 cc/30 min, the Formulation Drilling-Mud II yields 5.8 cc/30 min, the Formulation Drilling-Mud III yields 5.5 cc/30 min, the Formulation Drilling-Mud IV yields 5.8 cc/30 min, and the Formulation Drilling-Mud V yields 5.4 cc/30 min. Meanwhile, the specification is $\leq$ 6 cc/30 min [18][19]. In these results, all the formulations have fulfilled the specification. So that the mud formulation is good at controlling the filtering rate.

3.7 Api mud cake measurement

For API Mud Cake, the Formulation Drilling-Mud I yields 0.98 mm, the Formulation Drilling-Mud II yields 0.68 mm, the Formulation Drilling-Mud III yields 0.58 mm, the Formulation Drilling-Mud IV yields 0.73 mm, and the Formulation Drilling-Mud V yields 0.77 mm. Meanwhile, the specification is <1.5 mm [18][19]. From the test results, all the formulations have fulfilled the specification. So that it can be categorized as good mud.

3.8 K^+ measurement

At the K^+ measurement, all the formulations yield 36216 mg/l. Meanwhile, the specification of $\geq$ 33000 mg/l [18][19]. From the results, all formulations of drilling mud have fulfilled the specification to prevent shale development.

3.9 Hthp filtrate measurement

In HTHP Filtrate testing, the Formulation Drilling-Mud I yields 19 ml/30 min, the Formulation Drilling-Mud II yields 19 ml/30 min, the Formulation Drilling-Mud III yields 18 ml/30 min, the Formulation Drilling-Mud IV yields 19 ml/30 min, and the Formulation Drilling-Mud V yields 19.2 ml/30 min. Meanwhile, the specification is $\leq$ 2 ml/30 min [18][19]. The results of all tested formulations show that all parameters meet the specifications.

3.10 Hthp mud cake measurement

In the test of HTHP Mud cake, the Formulation Drilling-Mud I yields 1.78 mm, the Formulation Drilling-Mud II yields 1.98 mm, the Formulation Drilling-Mud III yields 1.97 mm, the Formulation Drilling-Mud IV yields 1.88 mm, and the Formulation

Drilling-Mud V yields 1.98 mm. Meanwhile, the specification was ≤ 2 mm [18][19]. These results indicate that all formulations have met the drilling-mud specifications. After rheological testing, then continued with testing for the prevention of swelling using Linear Swell Meter.

3.11 Linear swell meter testing results

Before testing the mud of Polymers, KCl polymers, and KCl Polymers with different Soltex compositions, firstly testing the development of shale to water is carried out to determine the extent to which the maximum shale development occurs because the reactive shale absorbs water. From the shale development testing that has been done, the results are 59.60%. This result shows that the development of shale is too high because shale easily develops when it is directly in contact with water. So, a linear swell meter test was carried out on all five types of mud. From the results of linear swell meter tests, it was found that the ratio of water with each type of mud was Polymer mud, KCl Polymer, and KCl Polymer with the composition of Soltex 2 ppb, 4 ppb, and 6 ppb, indicating that the percentage of water tested for shale development was very high. Decreasing the percentage of swelling between water and Polymer mud by 28.5%, water with KCl Polymer at 31.3%, water with KCl Polymer + Soltex 2 ppb at 33.2%, then water with KCl Polymer + Soltex 4 ppb at 38.4%, and water with KCl Polymer Soltex 6 ppb at 40.7%. Figure 1 displays the outcomes of shale development using several substances, namely water, polymer mud, polymer KCl, and polymer KCl with varied Soltex concentrations of 2 ppb, 4 ppb, and 6 ppb.

4 Conclusion

The results using the linear swell meter test showed that the rate of clay development (swelling) was 31.10% in polymer mud, 28.30% in KCl polymer, 26.40% in KCl polymer with Soltex 2 ppb, 21.20% in KCl polymer with Soltex 4 ppb, and 18.90% in KCl polymer with Soltex 6 ppb. Meanwhile for the swelling percentage reduction was as follows: 28.5% for water and polymer mud, 31.3% for water with KCl polymer, 33.2% for water with KCl polymer + Soltex 2 ppb, 38.4% for water with KCl polymer + Soltex 4 ppb, and 40.7% for water with KCl polymer + Soltex 6 ppb.

Based on the results and discussions in the previous section, we can conclude that Soltex 4 ppb has a lower material utilization compared to Soltex 6 ppb. The most effective mud type for preventing swelling is KCl Polymer with a concentration of Soltex at 4 parts per billion (ppb). The linear swell meter data indicate that the difference between Soltex concentrations of 4 ppb and 6 ppb is not statistically significant (**Fig. 1**).

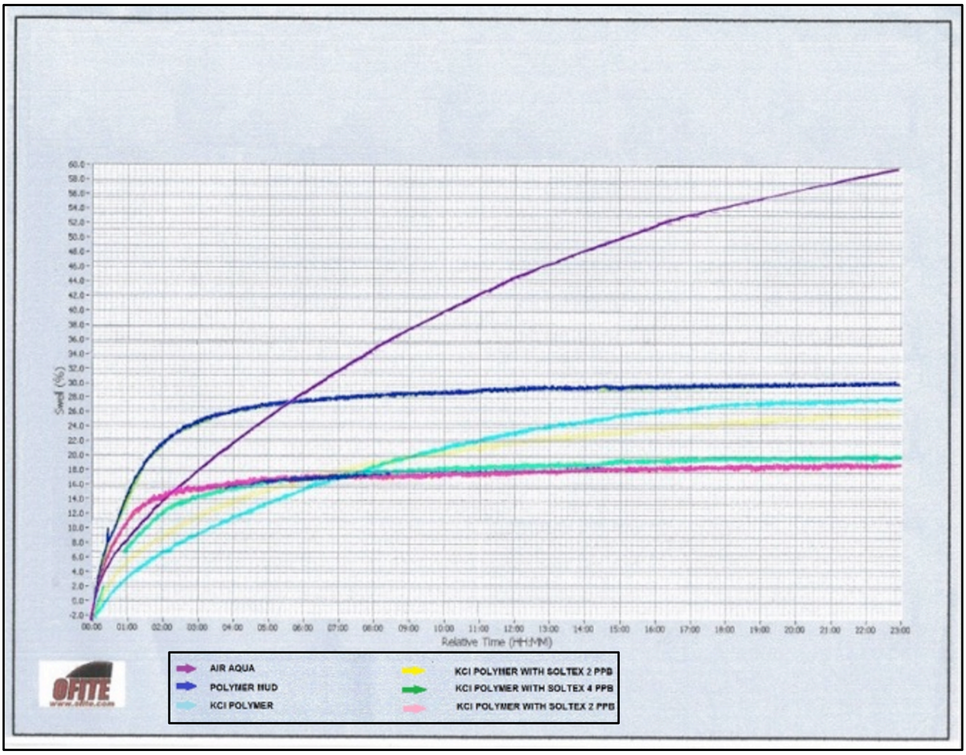

Fig. 1 Summary of Shale Development Outcomes

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