

Evaluation of Cutting Transport Efficiency in KCl Polymer Drilling Mud with Poly Anionic Cellulose Low Viscosity (PAC LV) Additive

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Abstract.

Effective transport of drilled cuttings out of the wellbore is a key requirement for maintaining drilling performance, since poor hole cleaning can trigger operational problems such as pipe sticking and inefficient circulation. This research examines how Poly Anionic Cellulose Low Viscosity (PAC LV) affects the cuttings-carrying performance of KCl Polymer water-based drilling mud. Two mud samples containing different PAC LV dosages were formulated and tested to obtain their density, plastic viscosity, yield point, gel strength, mud cake thickness, and filtration behavior. These rheological results were then applied to three engineering indicators, namely the Cutting Carrying Index (CCI), Cutting Transport Ratio (CTR), and Cutting Concentration in Annulus (CCA), to quantify cuttings transport performance. The findings show that raising the PAC LV dosage strengthens the mud's rheological profile, reflected in higher density, plastic viscosity, yield point, and gel strength, without compromising filtration quality. Both formulations produced CCI values above 1, CTR values exceeding 50%, and CCA values under 5%, confirming adequate cuttings-carrying capability and satisfactory hole-cleaning performance. Overall, the study confirms that PAC LV-treated KCl Polymer mud can deliver consistent rheological behavior and reliable cuttings removal under the tested conditions, contributing to safer and more efficient drilling operations.

Keywords: KCl Polymer, PAC LV, drilling mud, cuttings transport, hole cleaning.

1. INTRODUCTION

Among the components involved in oil and gas well construction, drilling fluid plays a particularly decisive role, since it governs drilling efficiency, wellbore integrity, and overall operational safety. Its functions span controlling formation pressure, cooling and lubricating the bit, supporting the wellbore wall, and carrying drilled solids from the bottom of the hole to the surface. Of these functions, cuttings transport deserves particular attention, because when hole cleaning is insufficient, cuttings tend to build up in the annulus. This buildup is associated with higher torque and drag, slower penetration rates, stuck pipe events, weaker cement jobs, and longer non-productive time (Al-Rubaii et al., 2023; Baker, 1995; Busahmin et al., 2017; M-I., 2001; Robinson & Morgan, 2004; Rubiandini, 2009).

How well cuttings are transported depends heavily on the rheological behavior of the drilling fluid itself. Properties such as plastic viscosity, yield point, and gel

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strength dictate how effectively the fluid can keep solids suspended and moving, whether the mud is circulating or momentarily static. For this reason, fine-tuning the mud formulation is a necessary step toward uninterrupted cuttings removal and steady drilling performance (Bridges & Robinson, 2020).

Among the various drilling fluid systems, water-based muds continue to dominate field applications because they are economical, environmentally friendlier, and flexible to work with. Within this category, KCl Polymer mud is frequently selected for shale intervals, since the potassium chloride component limits clay swelling and hydration, while the polymer content boosts viscosity and supports wellbore stability (Kementerian Pendidikan dan Kebudayaan Republik Indonesia, 2013). Poly Anionic Cellulose Low Viscosity (PAC LV) is one such polymer additive, serving simultaneously as a fluid-loss control agent and a rheology enhancer. Through its dual role in limiting filtrate loss and improving suspension behavior, PAC LV is anticipated to strengthen the hole-cleaning performance of the mud system (Agung & Hamid, 2015).

Although PAC LV is already widely applied in water-based systems, the bulk of existing studies center on its filtration-control and general rheological contributions. Relatively few studies have examined its specific impact on cuttings transport using quantitative indicators such as the Cutting Carrying Index (CCI), Cutting Transport Ratio (CTR), and Cutting Concentration in Annulus (CCA). Research that pairs PAC LV specifically with KCl Polymer mud systems under controlled laboratory conditions remains even scarcer.

This study, therefore sets out to determine how adding PAC LV influences the cuttings-transport behavior of KCl Polymer drilling mud, combining laboratory characterization with engineering-based analysis. The work covers measurement of density, plastic viscosity, yield point, gel strength, and filtration properties, followed by evaluation through the CCI, CTR, and CCA approaches. It is hoped that the resulting insights into the link between mud rheology and cuttings transport will help guide the formulation of water-based muds that clean holes more effectively and lower operational risk during drilling.

II. METHODS

This research was designed to assess how Poly Anionic Cellulose Low Viscosity (PAC LV) affects the cuttings-transport efficiency of KCl Polymer water-based drilling mud. Two mud formulations, differing only in PAC LV dosage, were prepared in the laboratory and characterized for their physical and rheological behavior. The resulting parameters were then applied to the Cutting Carrying Index (CCI), Cutting Transport Ratio (CTR), and Cutting Concentration in Annulus (CCA) methods to gauge each formulation's cuttings-carrying capability. In broad terms, the

research workflow proceeded through mud preparation, laboratory testing, cuttings-transport calculation, and comparative analysis of how PAC LV dosage relates to hole-cleaning outcomes.

2.1 Research Design

An experimental laboratory design combining quantitative measurement with descriptive interpretation was used to assess the cuttings-transport performance of PAC LV-treated KCl Polymer water-based mud. The central aim was to trace how changes in PAC LV concentration alter the mud's rheological character and, in turn, its hole-cleaning effectiveness.

2.2 Materials and Mud Formulation

Both KCl Polymer mud samples were built on a freshwater base. Beyond the base fluid, the formulation included potassium hydroxide (KOH) to regulate pH, bentonite to provide viscosity, PAC LV for filtration control and rheology adjustment, potassium chloride (KCl) to inhibit shale swelling, barite to adjust mud weight, and a defoamer to limit foam generation while mixing.

Table 1. Composition of KCl Polymer Drilling Mud Formulations

Sample 1			Sample 2	
No	Component	Weight	Component	Weight
1	Aquades (Fresh Water)	325 (ml)	Aquades (Fresh Water)	320 (ml)
2	KOH	0,50 gram	KOH	0,75 gram
3	Bentonite	6 gram	Bentonite	7,00 gram
4	PAC LV	2,50 gram	PAC LV	3,50 gram
5	KCl	15,00 gram	KCl	17,00 gram
6	Barite	20,00 gram	Barite	30,00 gram
7	Defoamer	1,50 gram	Defoamer	2,00 gram

Referring to Table 1, the PAC LV dosage was deliberately varied between the two samples so that its effect on mud properties and cuttings-transport performance could be isolated, while the rest of the KCl Polymer water-based formulation was kept consistent.

2.3 Laboratory Testing

Once mixed, each sample underwent a series of laboratory tests covering density, plastic viscosity (PV), yield point (YP), gel strength, mud cake thickness, and filtration loss. These specific parameters were chosen because of their direct bearing on how well cuttings can be suspended and carried through the annulus.

Results from this rheological testing were fed directly into the cuttings-transport calculations and the side-by-side comparison of the two formulations.

2.4 Cuttings Transport Evaluation

The efficiency of cutting transport was evaluated using three engineering indicators:

- **Cutting Carrying Index (CCI)**, reflecting the mud's carrying capacity; a value above 1 is taken as satisfactory.
- **Cutting Transport Ratio (CTR)**, expressing the share of cuttings successfully moved through the annulus; values exceeding 50% denote acceptable performance.
- **Cutting Concentration in Annulus (CCA)**, capturing the fraction of cuttings left behind in the annular space; values under 5% point to efficient hole cleaning with little accumulation.

Alongside these three indices, annular and slip velocity calculations were also incorporated as supporting hydraulic checks to better characterize how cuttings moved under the tested conditions.

2.5 Data Analysis

Results were examined descriptively, with the two formulations compared across density, plastic viscosity, yield point, gel strength, mud cake thickness, and filtration behavior to gauge the effect of PAC LV dosage.

These rheological figures were then carried forward into the CCI, CTR, and CCA calculations, which were benchmarked against the standard performance thresholds (CCI > 1, CTR > 50%, CCA < 5%) to judge each formulation's transport effectiveness and hole-cleaning adequacy. The relationship between rheology and transport efficiency was finally interpreted to single out the formulation offering the stronger overall drilling performance.

III. RESULT AND DISCUSSION

This section presents the experimental results obtained from the physical and rheological characterization of KCl Polymer drilling mud containing different concentrations of Poly Anionic Cellulose Low Viscosity (PAC LV). The measured properties were subsequently used to evaluate the cuttings transport performance of each mud formulation using the Cutting Carrying Index (CCI), Cutting Transport Ratio (CTR), and Cutting Concentration in Annulus (CCA). The discussion focuses on the influence of PAC LV concentration on mud rheology and its implications for hole-cleaning efficiency under the investigated laboratory conditions.

3.1 Physical and Rheological Properties of KCl Polymer Drilling Mud

Table 2 summarizes the laboratory measurements for the two KCl Polymer formulations, covering density, plastic viscosity (PV), yield point (YP), flow behavior index (n), consistency index (K), gel strength, and mud cake thickness, properties that together determine how capably the mud suspends and carries drilled solids.

Table 2. Physical and Rheological Properties of KCl Polymer Drilling Mud

Parameter	Sample 1	Sample 2
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Density (ppg)	9,1	9,6
Plastic Viscosity (cp)	12	17
Yield Point (lb/100 ft ²)	23	46
n	0,43	0,34
K	2,46	7,34
Kcci	1260,54	3752,34
Gel Strength 10 s	0,6	3
Gel Strength 10 m	0,5	6,1
Mud Cake (cm)	0,3	0,4

The data in Table 2 show a clear rheological improvement as PAC LV dosage increased. Sample 2 reached a higher density (9.6 ppg) compared with Sample 1 (9.1 ppg), pointing to a rise in solids content and, by extension, carrying capacity. Plastic viscosity climbed from 12 CP to 17 CP, consistent with stronger particle-to-particle interaction resisting flow.

A more pronounced shift appeared in the yield point, which rose from 23 lb/100 ft² in Sample 1 to 46 lb/100 ft² in Sample 2, evidence of a markedly improved ability to keep cuttings suspended and moving during circulation. At the same time, the flow behavior index (n) dropped from 0,43 to 0,34, signaling stronger shear-thinning behavior: the mud retains enough viscosity at low shear rates yet still flows more freely once shear rates climb.

The consistency index (K) likewise rose substantially, from 2.46 to 7.34, reinforcing the picture of improved rheology overall. Gel strength readings taken at 10 seconds and 10 minutes followed the same upward trend, pointing to a better capacity for holding cuttings in suspension whenever circulation pauses. Mud cake thickness edged up slightly as well, suggesting PAC LV helped form a more stable filter cake without sacrificing filtration quality.

Taken together, these results confirm that adding PAC LV meaningfully strengthens the physical and rheological profile of KCl Polymer mud, which in turn should support better cuttings suspension, transport, and hole cleaning.

3.2 Evaluation of Cuttings Transport Efficiency of KCl Polymer Drilling Mud with PAC LV

Building on the rheological data, cuttings-transport performance was next evaluated through the CCI, CTR, and CCA indicators, which jointly describe the mud's

capacity to lift cuttings off the bottom, move them through the annulus, and keep them from accumulating excessively.

The calculation reported in this section corresponds to a 12¼-inch interval drilled with 9⅝-inch production casing, covering a measured depth range of 1,672.95–2,712.07 ft. The drilling parameters required for the calculation, namely depth, mud density, hole inclination, rheology, rate of penetration (ROP), rotary speed (RPM), flow rate, cutting density, cutting diameter, and cutting concentration, were compiled from the Daily Drilling Report (DDR), Daily Mud Report (DMR), and Final Well Report (FWR) covering this interval and are summarized in Table 3.

Table 3. Drilling Parameters Used for the 12¼-inch Interval

Parameter	Value
Depth (ft, TVD)	1.672,95 – 2.712,07
Inclination (deg)	15,01
ROP (ft/hr)	93,29
RPM	186
Flow rate (gpm)	728
Cutting density (ppg)	22,56
Cutting diameter (in)	0,08
Cutting concentration	2,16

Combining the rheological properties in Table 2 with the drilling parameters in Table 3, annular velocity and critical velocity were calculated for every component of the bottom hole assembly (BHA) to establish the flow regime prevailing in the annulus at each position, as listed in Table 4. The results indicate that flow stayed laminar along nearly the entire string, the only exception being the stabilizer, where the flow turned turbulent. This shift is explained by the stabilizer's outside diameter being close in size to the borehole itself, which drives the local annular velocity above its critical value. Laminar flow is generally favored for cuttings transport because it moves material steadily toward the surface, whereas turbulent flow can let cuttings fall back during lifting and raise the likelihood of stuck pipe or wellbore sloughing. Variation in annular velocity along the string mainly reflects differences in pipe outside diameter, since a larger outside diameter narrows the annular flow area and raises local velocity;

critical velocity, in turn, is governed primarily by mud weight, plastic viscosity, and yield point.

Table 4. Annular Velocity, Critical Velocity, and Flow Regime by BHA Component

Slip velocity was then computed using the equation appropriate to each component's

BHA Component	Annular Velocity (ft/s)	Critical Velocity (ft/s)	Flow Regime
PDC Bit	3,454	5,655	Laminar
Motor	3,454	5,655	Laminar
Float Sub	3,454	5,655	Laminar
Stabilizer	24,772	10,079	Turbulent
MWD/LWD/PWD	3,554	5,710	Laminar
Drill Collar #1	3,454	5,655	Laminar
Jar	3,534	5,699	Laminar
Drill Collar #2	3,454	5,655	Laminar
Crossover Sub	3,454	5,655	Laminar
HWDP	2,377	4,895	Laminar
Drill Pipe	2,377	4,895	Laminar

flow regime, since laminar and turbulent conditions are governed by different relationships; the corrected slip velocity, adjusted for wellbore inclinations below 45°, was obtained next to support the Cutting Transport Ratio (CTR) calculation, with both sets of values listed in Table 5. Slip velocity depends on cutting density, cutting diameter, mud density, and annular viscosity; a higher annular viscosity lowers slip velocity, which slows the rate at which cuttings settle within the annulus and therefore favors more efficient transport toward the surface.

Table 5. Slip Velocity and Corrected Slip Velocity by BHA Component

BHA Component	Slip Velocity (ft/s)	Corrected Slip Velocity (ft/s)
PDC Bit	0,616	0,571
Motor	0,616	0,571

Float Sub	0,616	0,571
Stabilizer	0,531	0,493
MWD/LWD/PWD	0,623	0,578
Drill Collar #1	0,616	0,571
Jar	0,622	0,577
Drill Collar #2	0,616	0,571
Crossover Sub	0,616	0,571
HWDP	0,517	0,480
Drill Pipe	0,517	0,480

The corrected slip velocity was carried forward to determine the annular area point, the minimum annular velocity (V_{min}), and the minimum required flow rate (Q_{min}) for each BHA component, presented in Table 6. The annular area point ranged from 0.084 to 0.121 bbl/ft, a value set by hole size and pipe outside diameter, since a smaller outside diameter widens the annular flow area and increases the annular area point. V_{min} ranged from 1.917 to 15.470 ft/s, shaped by corrected slip velocity, ROP, cutting concentration, hole size, and pipe outside diameter, with a higher corrected slip velocity pushing V_{min} higher. Q_{min} followed in the range of 454.446 to 586.965 gpm, rising whenever either the annular area point or V_{min} increased. Because an actual circulation rate below the calculated Q_{min} would leave cuttings prone to settling in the annulus, the annular area point, V_{min} , and Q_{min} together form the basis for the CTR, CCA, and CCI values summarized in Table 7.

Table 6. Annular Area Point, Minimum Velocity (V_{min}), and Minimum Flow Rate (Q_{min}) by BHA Component

BHA Component	Annular Area Point (bbl/ft)	V_{min} (ft/s)	Q_{min} (gpm)
PDC Bit	0,084	2,660	560,319
Motor	0,084	2,660	560,319
Float Sub	0,084	2,660	560,319
Stabilizer	0,012	15,470	454,446
MWD/LWD/PWD	0,081	2,727	558,384

Drill Collar #1	0,084	2,660	560,319
Jar	0,082	2,713	558,777
Drill Collar #2	0,084	2,660	560,319
Crossover Sub	0,084	2,660	560,319
HWDP	0,121	1,917	586,965
Drill Pipe	0,121	1,917	586,965

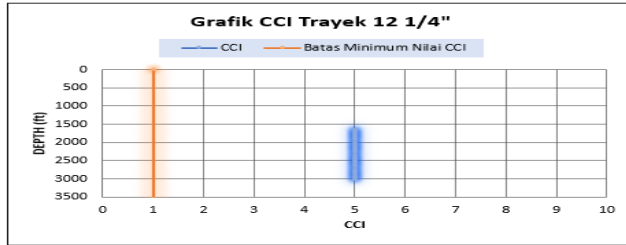
Table 7. Cutting Carry Index (CCI), Cutting Transport Ratio (CTR), and Cutting Concentration in Annulus (CCA) by BHA Component

BHA Component	CCI	CTR (%)	CCA (%)
PDC Bit	5,943	83,463	2,036
Motor	5,943	83,463	2,036
Float Sub	5,943	83,463	2,036
Stabilizer	42,624	98,012	2,138
MWD/LWD/PWD	6,115	83,729	2,037
Drill Collar #1	5,943	83,463	2,036
Jar	6,080	83,675	2,037
Drill Collar #2	5,943	83,463	2,036
Crossover Sub	5,943	83,463	2,036
HWDP	4,090	79,801	2,033
Drill Pipe	4,090	79,801	2,033

As shown in Table 7, the resulting values follow the pattern reported earlier: CCI spans 4.090–42.624, comfortably above the minimum threshold of 1; CTR spans 79.801%–98.012%, well above the 50% benchmark; and CCA stays within 2.033%–2.138%, safely under the 5% ceiling. These values are tied to a power-law carrying-capacity constant (K_{cci}) of 1260.54, which is itself governed by the plastic viscosity, yield point, and flow behavior index (n) reported in Table 2: a lower n raises K_{cci} and, in turn, raises CCI, while PV and YP shape n itself, so the three rheological parameters act jointly on the mud's cuttings-carrying capacity. Every CCI value obtained exceeds

1, satisfying the threshold proposed by Al Rubaii (2018) and confirming that cuttings were lifted to surface effectively across the evaluated interval.

Fig 1: Cutting Carry Index (CCI) profile across the 12¼-inch interval, plotted against the minimum threshold.



Across the evaluated section, the CCI curve sits well clear of the orange threshold line, staying above 4 throughout the depth range and never dropping anywhere near the minimum value of 1. This confirms that cuttings were lifted toward the surface without meaningful settling at any point along this interval, so the section shows no sign of a hole-cleaning problem. CCI itself is driven by a combination of annular velocity, mud density, and the mud's rheological character, specifically the power-law consistency index (K, built from plastic viscosity and yield point) together with the flow behavior index (n); these factors jointly set how much carrying capacity the fluid has at any given depth. (One component, the stabilizer, returns a markedly higher CCI of 42.624 because of its locally elevated annular velocity — its value sits well outside this 0–10 scale, so it's shown separately in the bar-chart Figure 1 from the earlier table.)

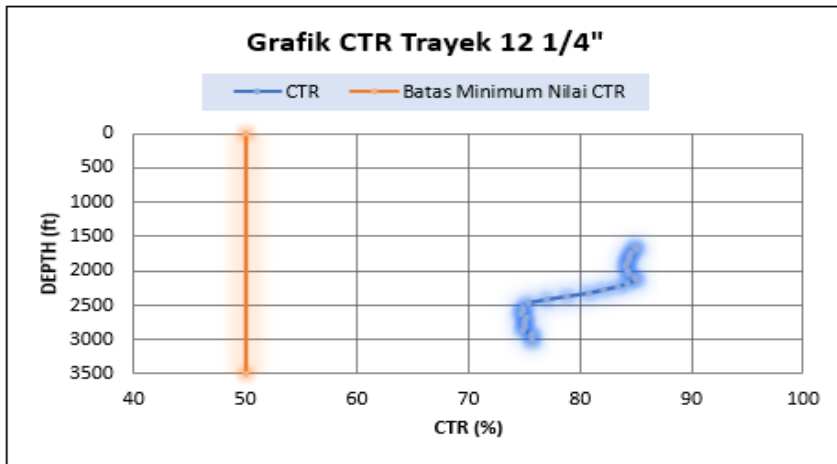


Fig 2: Cutting Transport Ratio (CTR) profile across the 12¼-inch interval, plotted against the minimum threshold

The CTR curve stays consistently above the 50% threshold line at every depth in this interval, ranging roughly between 80% and 84%. What drives the size of CTR here is mainly the corrected slip velocity: a smaller slip velocity, which goes hand in hand with a more viscous fluid in the annulus, narrows the gap between the minimum fluid velocity needed and the actual cutting-transport velocity, pushing CTR upward. Because the curve clears the threshold with margin to spare along the whole section, cuttings reached the surface without settling back into the wellbore, so no hole-cleaning issue is indicated here. A rise in CTR also has a knock-on effect on CCA: as the transport velocity increases, less cutting volume is left behind in the annulus, so hole-cleaning effectiveness improves and drilling can proceed more efficiently. (The stabilizer's CTR of 98.012% is excluded from this profile to keep it on the same scale as the source chart; it's captured in the earlier bar-chart figure instead.)

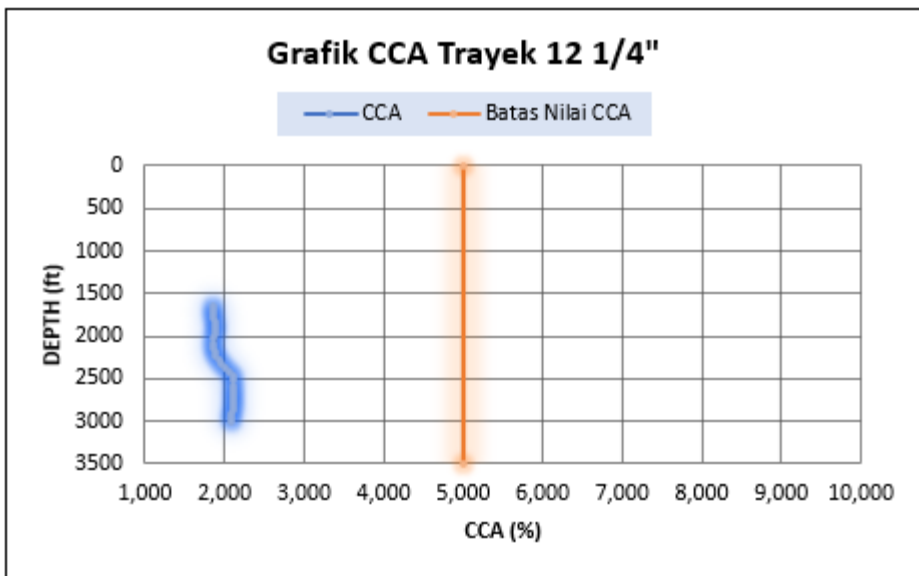


Fig 3 Cutting Concentration in Annulus (CCA) profile across the 12¼-inch interval

Every point on this curve sits well to the left of the orange maximum-threshold line, staying close to 2% across the whole interval instead of climbing toward the 5% ceiling. This means the circulating mud carried cuttings to surface without letting them build up in the annulus in any meaningful way. CCA moves opposite to CTR: the better the fluid is at transporting cuttings, the less material is left behind downhole, so the higher CTR values seen in Figure 2 line up with the consistently low CCA values here. Flow rate, ROP, and the flow behavior index (n) play a supporting role in shaping this relationship as well. Taken together with Figures 1 and 2, this profile confirms that

cuttings transport across the evaluated interval performed effectively and stayed within the recommended limits for every method applied.

IV. CONCLUSION

This study set out to determine how Poly Anionic Cellulose Low Viscosity (PAC LV) influences the physical, rheological, and cuttings-transport behavior of KCl Polymer drilling mud. Laboratory results confirmed that raising the PAC LV dosage strengthened several key rheological parameters, namely density, plastic viscosity, yield point, consistency index, and gel strength, which together improved the mud's capacity to suspend and carry cuttings while preserving stable hole-cleaning conditions.

Cuttings-transport performance, assessed via the CCI, CTR, and CCA indicators, confirmed that both formulations cleared the recommended thresholds. CCI values fell between 4.090 and 42.624 (above the 1.0 minimum), CTR values ranged from 79.801% to 98.012% (well past the 50% benchmark), and CCA values stayed between 2.033% and 2.138% (under the 5% ceiling), together pointing to efficient cuttings removal with minimal annular accumulation.

In summary, incorporating PAC LV into KCl Polymer drilling mud produces a clear rheological benefit and supports efficient cuttings transport. The resulting mud system is therefore well suited to improving hole-cleaning performance and contributing to safer, more efficient drilling operations under the conditions examined.

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