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Polypropylene Beads in Water-Based Mud for Cuttings Transportation Improvement

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Good wellbore cleaning is highly essential to cut off unnecessary spending due to related problems in drilling operations. Many new technologies have been introduced to address the poor wellbore cleaning issues. In this study, the experimental investigation focuses on the use of polypropylene-based polymer beads as a mechanism to enhance cuttings transportation in water-based mud. The primary objective of the experimental investigation is to observe the performance of the polymer beads in lifting the different sizes of drilled cuttings in water-based mud. Six different sizes of drilled cuttings, ranging from 0.50 to 3.34 mm, were used and the lifting performances were done at five different angles, i.e., 0° (vertical), 30°, 60°, 75°, and 90° (horizontal). From 250 conducted tests, the experimental results showed that the cuttings transport efficiency with the presence of polypropylene beads for small cuttings in basic water-based mud improved by 6-8 % for hole angles less than 30° and 4 % between angles of 60°-90°. Drilling mud with polymer beads transported smaller cuttings more efficiently compared to larger cuttings. Despite a relatively low recovery at highly deviated angles, the use of polymer beads has shown improvements in cuttings transportation. This approach might be suitable to transport smaller cuttings to the surface in directional wells.

1. Introduction

Drilling is risky and it requires high capital cost in upstream activities. The increase of drilling cost especially in drilling a deviated well is due to the increased number of several wellbore problems occurrence. One of them is due to poor wellbore cleaning jobs (Yu et al., 2004). In Malaysia, most of the reservoirs are unconsolidated or poorly consolidated. With the increasing number of horizontal and highly inclined wells drilled through these types of reservoirs, smaller-sand-sized-solids transportation is becoming a main concern during drilling operations (Duan et al., 2009). There are two dominant mechanisms that cause a protruding particle on a bed which is entrained into the suspension layer of a fluid. They are lifting and rolling mechanism that strongly depend on the relationship between the solids angle of repose and hole angle (Clark and Bickham, 1994). Duan et al. (2009) stated that solid particles on a bed are subjected to three types of forces, i.e., static, hydrodynamic and inter-particle forces. These forces, however, become dominant when the diameter of two closely neighboured particles are below 0.1 mm. Yu et al. (2004) reported that by increasing the drag force applied to cuttings, it helps cuttings to be lifted in vertical wells. They added that it must counteract gravitational forces acting on cuttings to minimize settling during both dynamic and static periods. The poorest removal rates generally occur with inclination angles in the region of 50° to 60° (Brown et al., 1989). Tomren et al. (1986) found that, at inclination angles of more than 35°, a cuttings bed starts to form and this situation becomes severe when the drill pipe lies on the low side of the annular. They also found that the increase reaches a plateau at approximately 65° and slight decrease around 70° to 90°. Cuttings transport efficiency is a measure of the number of cuttings that are transported out of the wellbore. The cuttings transport efficiency formula Lapeyrouse (2002) is:

$$CTE = \frac{Weight\ of\ drilled\ cuttings\ recovered}{Weight\ of\ initial\ drilled\ cuttings}\ X\ 100\ \% \quad (1)$$

An experiment carried out by Ozbayoglu et al. (2004) found that bed formations of smaller particles are much more difficult to be removed. Field experience and experimental observations showed that sand or smaller

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cuttings may be more difficult to clean under certain conditions (Duan et al., 2009). There are two driving mechanisms that act on the cuttings bed, i.e., fluid lift and drag forces. In turbulent flow, the lift force is more important than the drag force meanwhile in laminar flow the drag force dominates. The effect of the type of drill bit used is not as significant and it does not have a dynamic input in hole cleaning (Nazari et al., 2010). The steps taken when cuttings are not efficiently removed are to increase the mud viscosity or annular velocity. This however causes problems beneath the bit because the penetration rate is reduced. Therefore, a way to solve this problem is to understand the reasons for cuttings to settle. The slipping of cuttings are driven by the gravitational force (Fg) and drag force (Fd). According to Skalle (2011), in a deviated well, the forces acting on a cutting being transported upwards in a moving fluid are portrayed in Figure 1.

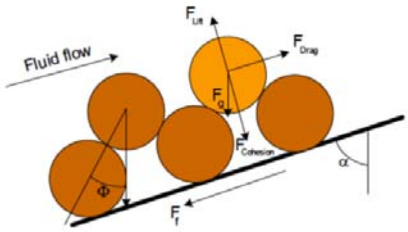


Figure 1: Forces acting on a particle at an active erosion site of cuttings bed (Skalle, 2011)

2. Materials and method

Over 250 runs were carried out using six different sizes of drilled cuttings, ranging from 0.50 to 3.34 mm, at five different hole inclinations, i.e., 0° (vertical), 30°, 60°, 75°, and 90° (horizontal), and in two different drilling mud systems which are basic water-based mud (WBM) and water-based mud with 1 % (by weight) polymer beads (WBMPB). In both phases, the mud contained bentonite, barite, and soda ash while the density was maintained at 120 kg/m^3 . The test section was built using a transparent acrylic pipe to allow observation of the mud flow behaviour (Figure 2). The pipe was 4.0 m long with 51 mm inner diameter (ID) and 53.3 mm outer diameter (OD). Inside this pipe was a 4.0 m long hollow PVC pipe with 20 mm OD. The polymer beads being an inert material, does not react with the drilling fluid. The experimental work was conducted using a lab-scale rig simulator at ambient temperature as shown in Figure 2. The following sequences of steps were used. The annular velocity was measured using an ultrasonic flow meter with transducers before the test section. After the circulated drilling mud has stabilised at the predetermined annular velocity of 0.78 m/s, 200 g of cuttings were injected into the cuttings feed hopper.

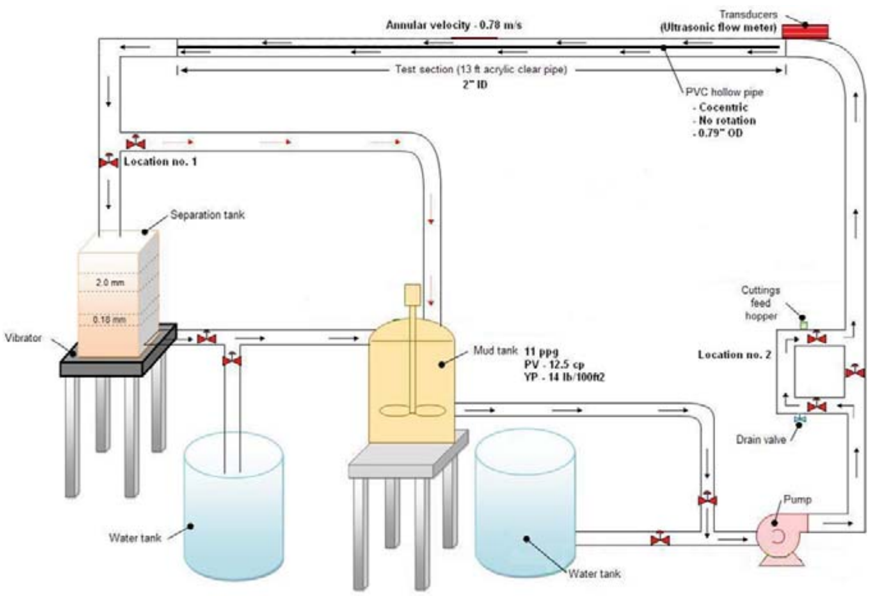


Figure 2: Schematic diagram of flow loop

3. Results and discussion

3.1 The effect of cutting size on cuttings transport efficiency

Figure 3a shows the recovery percentage of drilled cuttings against different sizes of cuttings in basic water-based mud (WBM). It can be seen that as the size of drilled cuttings increased, the cuttings transport efficiency (CTE) reduced for all angles of the hole. In vertical hole, the CTE for drilled cuttings size of 0.50 – 0.99 mm in WBM was 91 % and it reduced to 89 % as the size of drilled cuttings increased to 1.00 – 1.39 mm. As the size increased to 1.40 – 1.69 mm, a further reduction of CTE occurred. This is due to the increase in weight of drilled cuttings particles with respect to their sizes, i.e., 2.61 g/cc. This was supported by the worst performance shown by drilled cuttings size of 2.80 – 3.34 mm, i.e., the CTE was only 73 % at vertical angle.
Figure 3b shows the cuttings transport in water-based mud with polymer beads (WBMPB). It is observed that the pattern was similar to WBM in Figure 4. By comparing the drilled cuttings lifting performances, side by side, at particular angles of wellbore, it can be seen that with the presence of 1 % (by weight) of polymer beads in WBM, the CTE for all sizes improved, as shown in Figure 3b. Results showed that the cuttings transport efficiency improved by 8 % in the vertical hole when the drilled cuttings size of 0.50 – 0.99 mm was injected. As for the biggest cuttings size, i.e., 2.80 – 3.34 mm, an improvement was also observed where the CTE recorded was 79 % as compared to 73 % in basic WBM, according to Figure 3c. The size of cuttings is related to their dynamic behavior in a circulated fluid. Factors such as the terminal velocity, shear forces, drag forces, and buoyant forces between cuttings are affected by the properties of the cuttings and the flowing media (Wang et al., 2013). According to Skalle (2011), cuttings are transported by rolling motion in highly deviated wellbores. This rolling of particles happens when the rolling torque resulting from the drag and lift forces are able to overcome the counteracting torque from gravity and cohesion forces as illustrated in Figure 1. Thus, in order to have a good hole cleaning, efforts to counteract the gravitational and cohesion forces acting on drilled cuttings should be initiated. The idea behind this theory is to minimize the settling of drilled cuttings during both dynamic and static conditions (Yu et al., 2004). This phenomenon could mitigate the impact of drilled cuttings' weight. In the presence of polymer beads in the said drilling mud, the up-thrust force that acts on drilled cuttings particle can be improved. When 1 wt% of the polymer beads were added into the drilling fluid, they initiate a force by colliding and pushing the drilled cuttings in the direction of the mud flow. In addition to that, the low specific gravity of the polymer beads has provided an additional upward force, which is known as buoyancy force. This phenomenon minimizes the slip velocity of drilled cuttings which in turn minimizes the formation of cuttings bed. In the mathematical approach, the low slip velocity of particles lowers the Reynolds number of the particles in which would increase the drag coefficient (Onuoha et al., 2014). By doing so, the overall drag force applied to the drilled cuttings would increase and thereby enhances the cuttings transport efficiency.

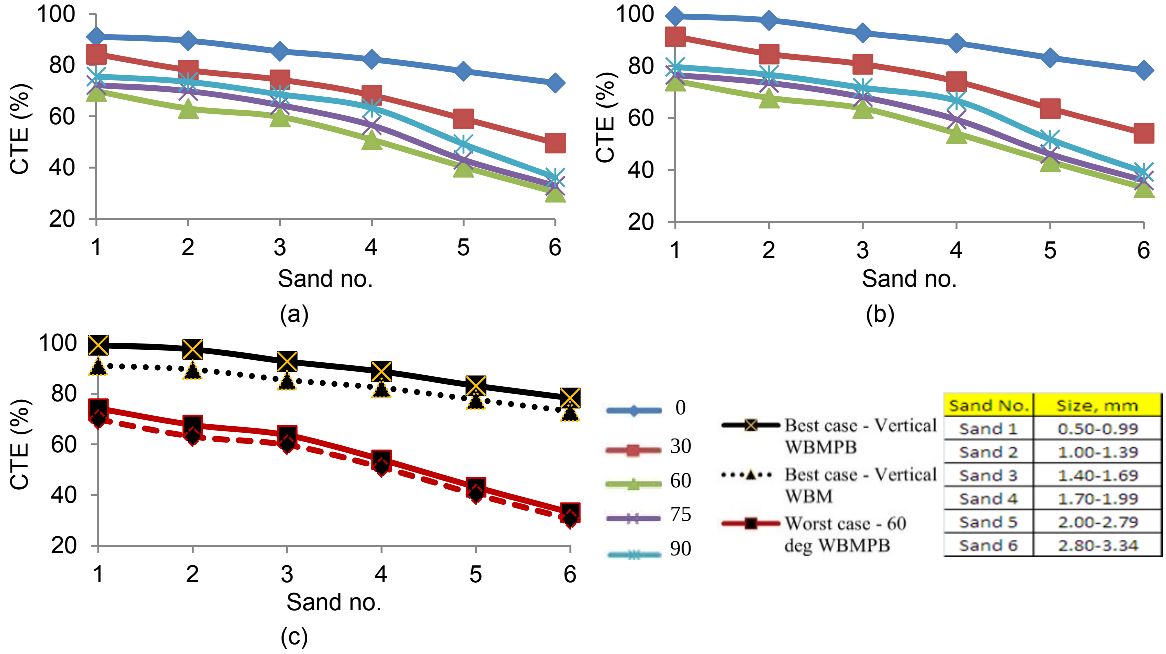
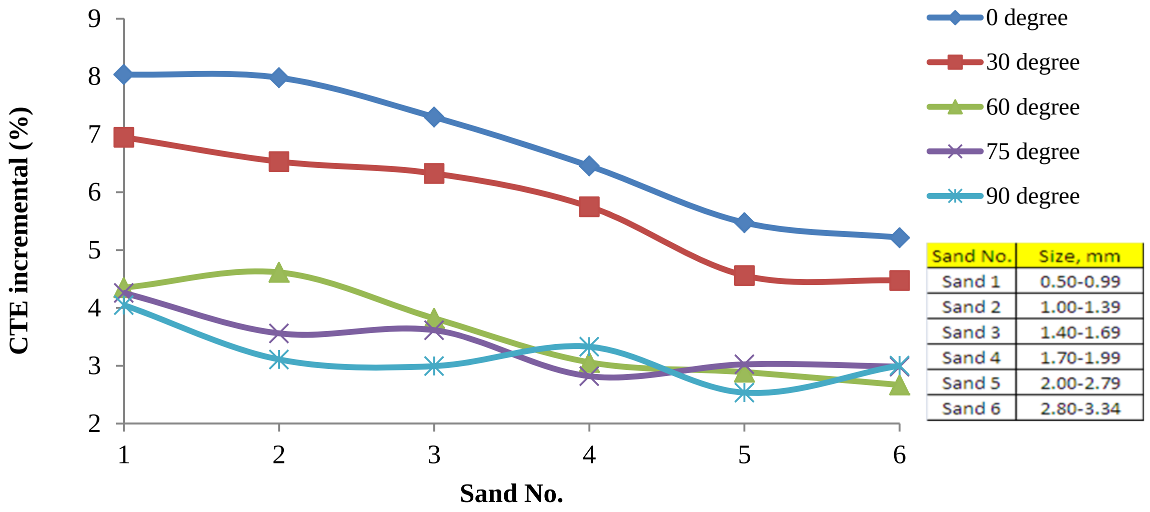


Figure 3: CTE of (a) WBM for different cuttings sizes, (b) WBMPB for different cuttings sizes and (c) Best and worst cases for different cuttings sizes in various mud.

3.2 Effect of cuttings sizes on CTE increment

Figure 4 shows the incremental CTE against the drilled cuttings sizes in WBMPB. It is observed that the CTE increment reduced proportionally to the size of drilled cuttings especially in vertical and 30° angled holes. As for drilled cuttings size of 0.50 – 0.99 mm, since they were smaller and lighter, the polymer beads were able to float and at the same time direct them by interfering with the settling of these cuttings effectively to the surface. Moving to the bigger size of cuttings, the CTE continued to drop. This was because the polymer beads only had enough force to direct the smaller sized cuttings up to the surface. This can be seen in Figure 4. By taking different hole angles into account, the CTE increments for small cuttings size (0.5-0.99 mm) were between 4 to 8 %. Meanwhile the CTE increments for the large cuttings size (2.8-3.34 mm) were between 2.7 to 5.3 %. Based on the above discussion, the presence of polymer beads in the drilling mud has produced a significant effect in transporting different sizes of drilled cuttings. From the data collected, polymer beads were found to be capable of transporting smaller cuttings effectively rather than the bigger ones including those of the same size as the polymer beads.



Sand No.	Size, mm
Sand 1	0.50-0.99
Sand 2	1.00-1.39
Sand 3	1.40-1.69
Sand 4	1.70-1.99
Sand 5	2.00-2.79
Sand 6	2.80-3.34

Figure 4: Incremental CTE for different cuttings sizes in WBMPB

3.3 The influence of hole angles on CTE

Figure 5a shows the CTE against the hole angle using basic WBM. It is shown that the hole angles affect the CTE regardless of the drilled cuttings sizes. For example, for cuttings sizes of 0.50 – 0.99 mm, it was found that vertical hole gives the best hole cleaning with 91 % CTE. As the geometry of the wellbore deviated to 30° from vertical, the CTE gradually decreased to 84 % and finally reached its lowest performance of 69 % at 60° inclination. This applies to all sizes of the drilled cuttings and mud systems. As the angle of the hole increased further to horizontal condition, the CTE was found to have improved marginally. The experimental results are in good agreement with findings by Pigott (1941), Tomren et al. (1986), and Brown et al. (1989). When polymer beads were added to basic mud, there was an increase in CTE for every hole angles, as shown in Figure 5b. The recovery percentage for both WBM (Figure 5a) and WBMPB (Figure 5b) at different hole angles, exhibits the same pattern. The poorest removal rates occurred at hole angle of 60°. A further increase in hole angle produced a marginal improvement in CTE. The improvement of CTE in the vertical hole was higher in comparison with the CTE in hole angle of 60°, i.e., 8 % incremental of CTE in vertical hole as compared to 4 % incremental in 60° angle hole as shown in Figure 5c. Unlike in the vertical wellbore, cuttings transports in the near horizontal wellbores are more difficult. This is because at critical angles between 30-60°, cuttings are harder to be transported. The upward lift of these cuttings faces obstacles from the geometry of the hole. The upper wall of the hole in deviated drilling, especially in critical angles, deflects the cuttings thus results in a cuttings bed formation. One of the best ways to remove cuttings from this difficult angle is if the cuttings are moving in a direction parallel to the mud flow. This is because the mud flow is flowing upwards according to the geometry of the hole. The addition of polymer beads into drilling fluid managed to increase the CTE as shown in Figures 5b and c. This is because the polymer beads increase the drag force by directing the cuttings to the direction of the mud flow.

3.4 Effect of different hole angles on CTE increment

Figure 5d shows the CTE increment against respective hole angles. As the angle deviates from vertical, the decrease of CTE was significant. The increment did not give a consistent trend for all the drilled cuttings sizes. This can be observed in Figure 5d when the inclination angle increased to 60°, 75°, and 90° (horizontal). At vertical, the drilled cuttings would move downward against the flow of drilling mud due to the forces of gravity. But the presence of the polymer beads in the drilling mud has signified the drilled cuttings movement upward due to the sufficient up thrust force in the same direction as the drilling mud. Therefore, the polymer beads could provide a net up thrust force which in turn would reduce the slip velocity. As in the deviated hole especially at angles between 60° to 90°, the inconsistency of the CTE increment was obvious. It is understood that in the inclination wellbore, the polymer beads and drilled cuttings particles were not flowing and interacting in the same space as in the vertical hole. Therefore, the sweeping effect did not work efficiently as expected at critical angles between 60° to 90°. Nevertheless, the CTE increments for different cuttings sizes at 0° and 30° were between 5.2 % to 8 % and 4.4 % to 7 % respectively. This means that adding polymer beads to drilling mud resulted in a significant improvement for hole angles less than 30°. Apart from that, Figure 5b also shows CTE increment of approximately 4 % to 4.5 % for small cuttings (0.5-0.99 mm) at angles between 60° to 90°. This result is however not observed in cuttings that are larger than (0.5-0.99 mm).

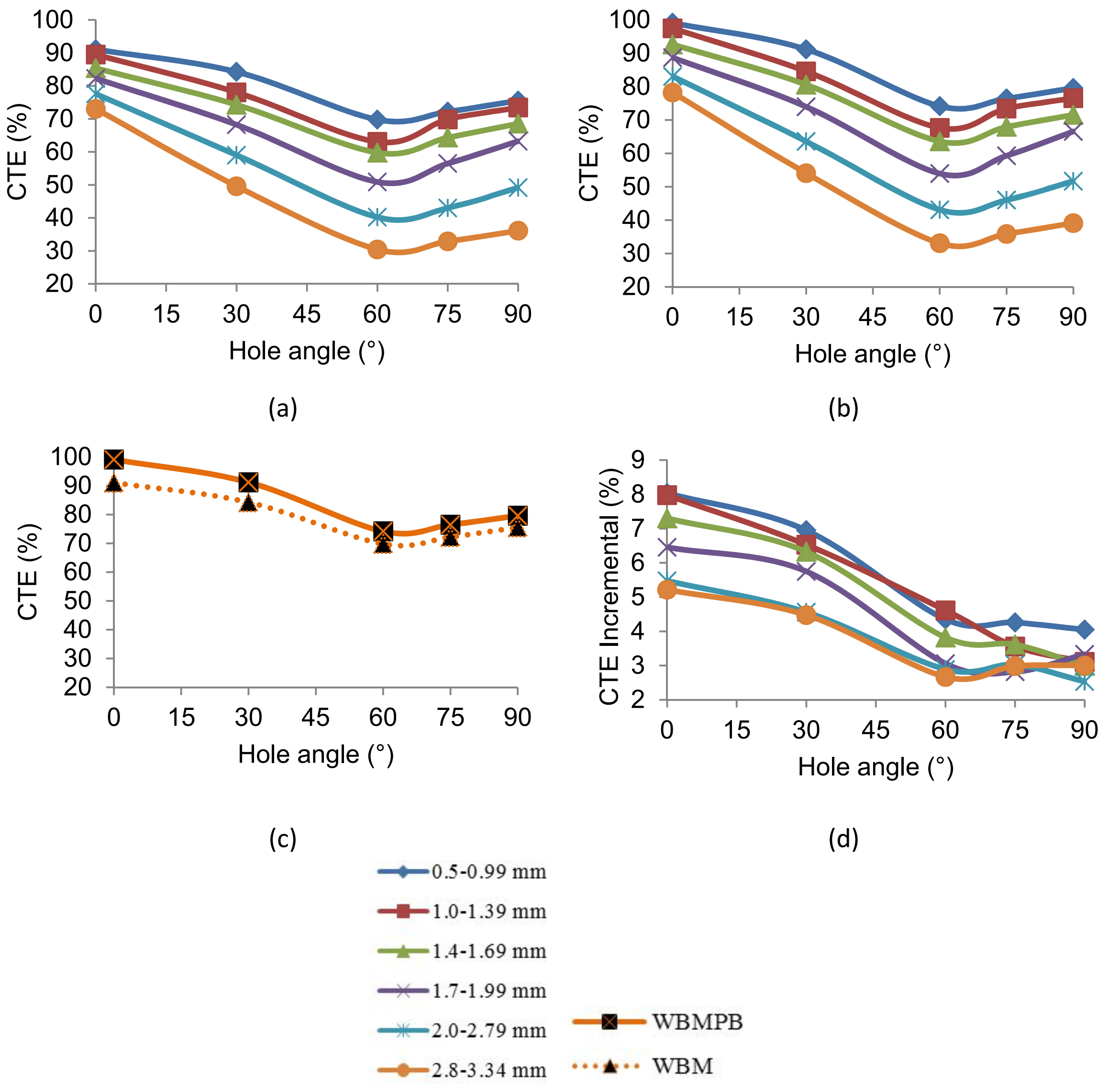


Figure 5: (a) CTE for WBM at different hole angles, (b) CTE for WBMPB at different hole angles, (c) CTE for smallest cuttings size at different hole angles and (d) CTE increment for WBMPB at different hole angles.

4. Conclusions

This study investigated the performance of polypropylene beads in lifting different sizes of drilled cuttings in water-based mud (WBM) with respect to wellbore angles. In this study, the influence of eccentricity and rotary of drill pipe as well as cuttings shape were not taken into consideration. Other parameters, such as mud density and pH, were kept constant throughout the experimental work. The important findings from this research work are as follows:

(1) The presence of a small quantity of polymer beads (i.e., 1 % (by weight)) in water-based mud could effectively improve wellbore cleaning especially in the vertical or near vertical hole.

(2) The performance of polymer beads in lifting smaller drilled cuttings was found to be better with high cuttings transport efficiency (CTE) with respect to the angles of the hole but it reduced as the drilled cuttings size approached or was close to the size of polymer beads.

(3) The polymer beads managed to improve the cuttings transport efficiency (CTE) at different hole angles because it increases the drag force by directing cuttings to the direction of the mud flow

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