

Improving the Cuttings Transport Performance of Water-based Mud Through the Use of Polypropylene Beads

(Meningkatkan Prestasi Pengangkutan Rincisan bagi Lumpur Dasar Air Menggunakan Manik Polipropilena)

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ABSTRACT

This research work presents the experimental results of the effect of polypropylene beads' concentrations in water-based mud on wellbore cleaning. A comparative study of cuttings transport performance (CTP) of water-based mud and water-based mud with polypropylene beads were carried out at different hole angles of 0°, 30°, 60°, 75° and 90° in a 13 ft (3.96 m) acrylic concentric annulus flow test section, having a 2 in (50.8 mm) casing ID and a fixed 0.79 in (20 mm) inner pipe OD. A total of 100 runs had been accomplished using fine sands (from Tanjung Balau, Johor Bahru, Malaysia), of size ranging from 5/127 - 6/127" (1.0 – 1.2 mm) and density 2.4 g/cc (2400 kg/m³), with the mud density and viscosity maintained at 9 ppg (1078 kg/m³) and 5 cp (0.005 Pa.s), respectively, in a flow velocity of 2.1 ft/s (0.64 m/s). Polypropylene beads used in this study have the following properties: 290 kg/cm² of tensile strength at yield, 0.86 g/cc (860 kg/m³) density, 4 mm (20/127") size, 82 R scale Rockwell hardness, 13,500 kg/cm² flexural modulus, 85°C heat deflection temperature at 4.6 kg/cm², 4 g/10 min melt flow rate at 230°C and spherical in shape. The experimental findings showed that commingling the basic mud with polypropylene beads has successfully introduced a buoyant force which was found to have improved the cuttings transport performance by more than 10% when weight concentration of the polypropylene beads was increased to 1.5% as compared with the performance obtained from the basic water-based mud. The improvement of cuttings transport performance was found to be more significant in a vertical hole.

Keywords: Cuttings transport performance; drilled cuttings; drilling mud; polypropylene beads; water-based mud

ABSTRAK

Penyelidikan ini mengenengahkan hasil kajian tentang kesan kepekatan berat manik polipropilena dalam lumpur dasar air terhadap pembersihan lubang telaga. Suatu kajian perbandingan terhadap prestasi pengangkutan rincisan bagi lumpur dasar air bercampur dengan manik-manik polipropilena berbanding lumpur dasar air tanpa manik polipropilena telah dijalankan pada sudut lubang yang berbeza, iaitu 0°, 30°, 60°, 75° dan 90°. Kajian melibatkan penggunaan paip akrilik sepanjang 13 kaki (3.96 m) yang memiliki bahagian ujian aliran anulus sepusat, yang terdiri daripada satu selongsong berdiameter dalam 2 in (50.8 mm) dan satu paip dalam tak putar berdiameter luar 0.79 in (20 mm). Sebanyak 100 uji kaji telah dijalankan menggunakan pasir halus dari Tanjung Balau, Johor Bahru, Malaysia, yang bersaiz 5/127 - 6/127" (1.0 – 1.2 mm) dan berketumpatan 2.4 g/cc (2400 kg/m³). Lumpur gerudi yang digunakan berketumpatan 9 ppg (1078 kg/m³) dan berkelikatan 5 cp (0.005 Pa.s), dengan purata halaju aliran di dalam paip ialah 2.1 ka/s (0.64 m/s). Manik-manik polipropilena yang digunakan dalam kajian mempunyai sifat-sifat berikut: Kekuatan tegangan, ketumpatan 0.86 g/cc (860 kg/m³), saiz 4 mm (20/127"), kekerasan 82 R pada skala Rockwell, modulus lenturan 13,500 kg/cm², suhu pesongan haba 85°C pada 4.6 kg/cm², kadar alir leburan 4 g/10 min pada 230°C dan berbentuk sfera. Hasil kajian menunjukkan bahawa campuran lumpur dasar air dengan manik-manik polipropilena berjaya menghasilkan suatu daya apung. Daya ini telah meningkatkan prestasi pengangkutan rincisan melebihi 10% apabila kepekatan berat manik polipropilena ditingkatkan kepada 1.5% berbanding prestasi lumpur dasar air tanpa manik polipropilena. Peningkatan prestasi pengangkutan rincisan adalah lebih ketara dalam lubang tegak.

Kata kunci: Lumpur dasar air; lumpur gerudi; manik polipropilena; prestasi pengangkutan rincisan; rincisan gerudi

INTRODUCTION

Over the years, drilling operations have been an indispensable aspect of oil and gas exploration and field development. A well designed drilling program will not only reduce the drilling cost and rig time, but would as well increase its presumed economic benefits during

exploitation through mitigation of complications and damages to the targeted zones.

On the strength of this premise, it is worthwhile to say that a proper understanding of all the influential parameters that affect drilled cuttings transport and consequent hole cleaning for an effective drilling process would be very

useful. However, previous researchers have done great works in unravelling the rationale behind the factors that affect the cuttings carrying capacity of drilling fluids. Parameters such as annular flow rate, rate of penetration, fluid density, effective fluid viscosity, cuttings size, cuttings density, well inclination and pipe/hole eccentricity play leading roles in cuttings transport performance of drilling fluid (Ozbayoglu et al. 2004; Stan & Avram 2014). In the same vein, other factors such as fluid flow regime and pipe rotation have also been observed to have a great impact on drilled cuttings transport in vertical, deviated, and horizontal wellbores (Ford et al. 1990; Ozbayoglu et al. 2008; Rooki et al. 2014; Tomren et al. 1986).

Due to the imperative nature of deviating a well directionally or horizontally during drilling operations, as desired in order to bypass many obstructions and to reach the targeted zones for an economic exploitation of oil and gas reserves, the petroleum industry has witnessed continuous research work for the improvement of the hole cleaning capabilities of the drilling fluids for an effective and efficient drilling operation. Thus, if drilling programs are not properly structured, its inherent problems such as excessive torque and drag, pipe sticking, increase in equivalent circulation density, resistance in drill string sliding, lost circulation, barite sag, difficulty in running casing and logging tools would prevail (Ali et al. 2012; Cameron 2001). However, these problems as aforementioned are most prevalent when deviating a wellbore along a planned target at a given lateral distance

and direction from vertical. Therefore, this paper discusses a new idea that has been realized in the form of using polypropylene beads, an inert material that would not alter the chemistry of the drilling mud when commingled together to improve the cuttings transport capacity of water-based mud.

EXPERIMENTAL SETUP AND MATERIALS

EXPERIMENTAL FLOW-LOOP

The experimental flow-loops shown in Figure 1, was designed and developed to satisfy the objective of this research work, which was to investigate the effect of polypropylene bead's weight concentrations in water-based mud would have on wellbore cleaning for the vertical, inclined and horizontal conditions of the annulus test section (i.e. the simulated wellbore). The components of the flow-loop comprised a concentric annulus test section of 13 ft (3.96 m) long acrylic pipe, with 2-in (50.8 mm) ID for the outer pipe and 0.79 in (20 mm) OD for the fixed inner pipe with both ends closed. The annulus test section was designed to allow the variation of its angles, which provided the means of investigating the effect of hole inclination angles (i.e. 0°, 30°, 60°, 75° and 90°) on the performance of the commingled polypropylene beads and water-based mud for cuttings transport. The mud was circulated using a 2-hp variable speed centrifugal pump which was connected to 132.1 gallons (500 L) capacity

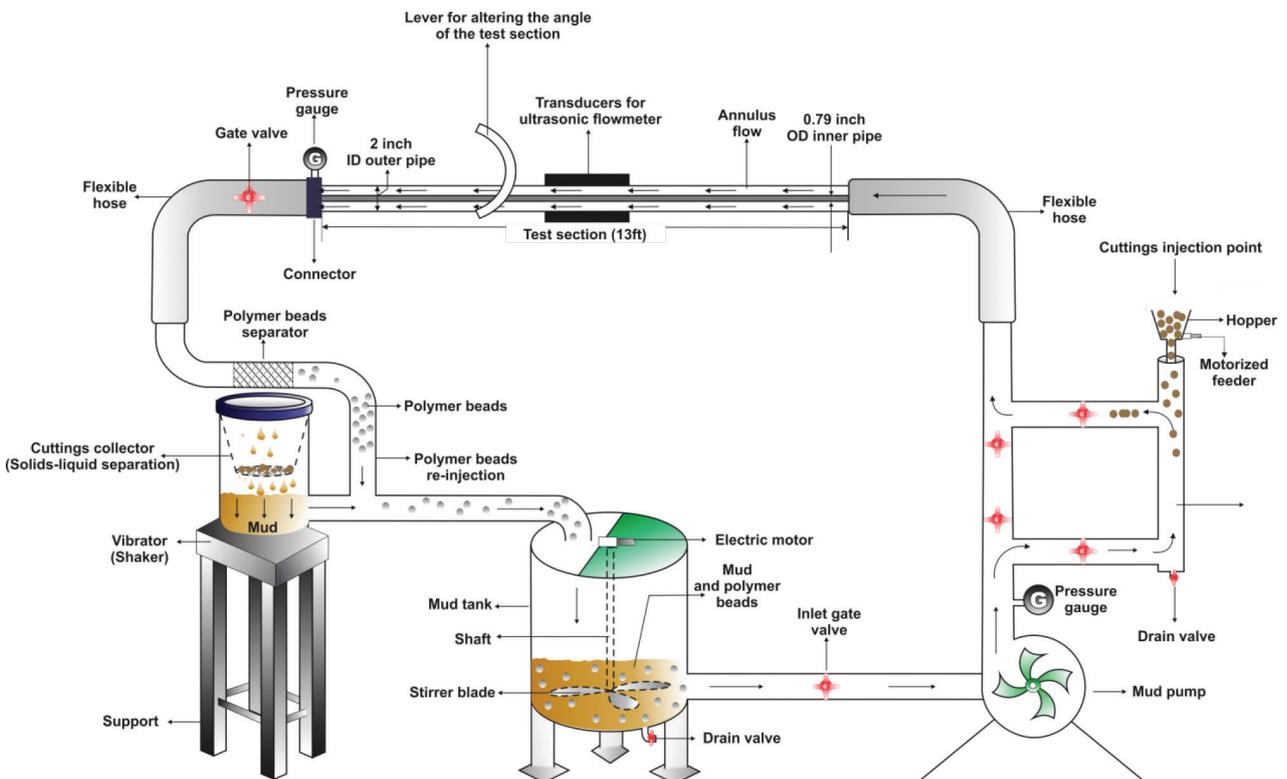


FIGURE 1. Experimental flow-loop

mud tank. Two separation systems were incorporated in the system to allow the separation of polypropylene beads from transported cuttings and mud using a 2 mm mesh separator; and the separation of transported drilled cuttings and mud using a cuttings collector fitted with mesh.

SIMULATED DRILLED CUTTINGS

Fine sands were used as solid particles or simulated drilled cuttings for this study, which was taken from Tanjung Balau Beach, Johor Bahru, Malaysia. The particles size was in the range between 5/127 - 6/127 (1.0 -1.2 mm) and of irregular shapes with density 2.4 g/cc (2400 kg/m³) as was determined using the standard ASTM D4253-00 (2006) testing method.

DRILLING MUD

American Petroleum Institute (2009) recommended practices were followed in the preparation of the water-based mud that was used in this research work. Bentonite was used as the viscosifier, barite as the weighting agent, and tap water as the continuous phase. However, in order to establish a justified basis for comparison between water-based mud containing different weight concentrations of polypropylene beads and a water-based basic mud for cuttings transport performance evaluation, the rheological properties were measured and kept constant throughout the experiment. Table 1 shows the components of the basic mud (i.e. laboratory scale) and the components of the basic mud with polypropylene beads of different weight concentrations that were used in accomplishing the research work. It can be seen that the proportion of barite requirement was increased slightly for different concentrations of polypropylene beads in the water-based mud because the introduction of the polypropylene beads has reduced the mixture density of the mud when blended together due to its light weight

that is less dense than water. The addition of barite has successfully kept the density and mud rheology constant in all the runs.

POLYPROPYLENE BEADS

Mass produced polypropylene-based polypropylene beads (PP) (Figure 2) were used in this research work, which have regular sizes of 0.16" (4 mm) and are of spherical in shape with density as determined via the ASTM D4253-00 (2006) testing method. To prepare the desired water-based muds with polymer beads, three weight percentages of polypropylene beads (0.5, 1.0 and 1.5 wt. %) were applied. The Differential Scanning Calorimeter (DSC) test conducted on both polypropylene beads showed that Polypropylene beads has a melting point temperature (T_m) of while Polyethylene polypropylene beads is thus enables Polypropylene polymers to be widely used in drilling operations including oilfields in Malaysia. However, the polypropylene-based polymer beads as being an inert material has no chemical properties.

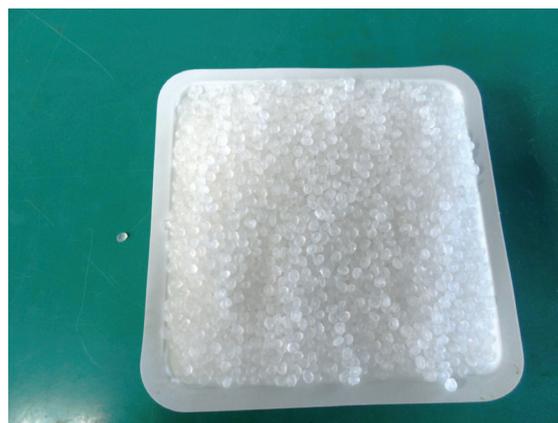


FIGURE 2. Polypropylene beads

TABLE 1. Formulations of drilling muds used in the current study

Type of drilling mud	Components	Rheological Properties				
		μ_a cp	μ_p cp	ρ ppg	YP lb/100 ²	GS lb/100 ft ² @ 10s - 10m
Basic water-based mud	Barite (110.5 g) + bentonite (40 g) + tap water (1400 mL)	7	5	9	4	2-15
Water-based mud with 0.5 wt. % of polypropylene beads	Barite (119 g) + bentonite (40 g) + polypropylene Beads (7.75g) tap water (1400 mL)					
Water-based mud with 1.0 wt. % of polypropylene beads	Barite (121.56 g) + bentonite (40 g) + polypropylene Beads (15.5 g) tap water (1400 mL)	7	5	9	4	2-15
Water-based mud with 1.5 wt. % of polypropylene beads	Barite (124.21 g) + bentonite (40 g) + polypropylene beads (23.25 g) tap water (1400 mL)	7	5	9	4	2-15

EXPERIMENTAL METHODS

The sand particles were sieved to the desired sizes and weighed into separate masses of 200 g (0.2 kg) each to serve as the test solid samples for different runs. The basic water-based mud of density 9 ppg (1078 kg/m³) and viscosity 5 cp (0.005 Pa.s) was then prepared in the mud tank as the drilling fluid. Mud circulation was done at ambient condition of 28°C using a variable speed centrifugal pump and it continued until a stabilized fluid flow rate was achieved as measured by an ultrasonic flow meter. A constant flow velocity of 2.1 ft/s (0.64 m/s) and flow rate of 17 gal/min (64 l/min) were maintained throughout the runs. Once the stable flow velocity was reached, the sand particles meant to be transported were injected into the system at an injection rate of 0.44 lbm/min (200 g/min) and the test period lasted for 6 min. The transported cuttings were collected, washed, dried and weighed in order to ascertain the actual mass of sands that were successfully transported through the concentric annulus test section, which indicated the cuttings carrying capacity of the test mud and otherwise known as the cuttings transport performance. The same procedure was repeated at different inclination angles of the annulus test section (i.e. 30°, 60°, 75° and 90°).

After all the runs have been made with the basic water-based mud, hence polypropylene beads of different weight concentrations (i.e. 0.5, 1.0 and 1.5%) were introduced into the said mud while the rheological properties were maintained constant to ensure conformity of both muds. The experiment was repeated by commingling the polypropylene beads with the mud as mentioned above, as such to ascertain its cuttings transport performance and comparison was made to that of the basic water-based mud to ascertain efficiency. The equation used to calculate the cuttings transport ratio (CTR) is given by (1) and a total of 100 runs were accomplished.

$$\text{Cutting transport ratio (\%)} = \frac{\text{Final dried weight}}{\text{Initial dried weight}} \times 100. \quad (1)$$

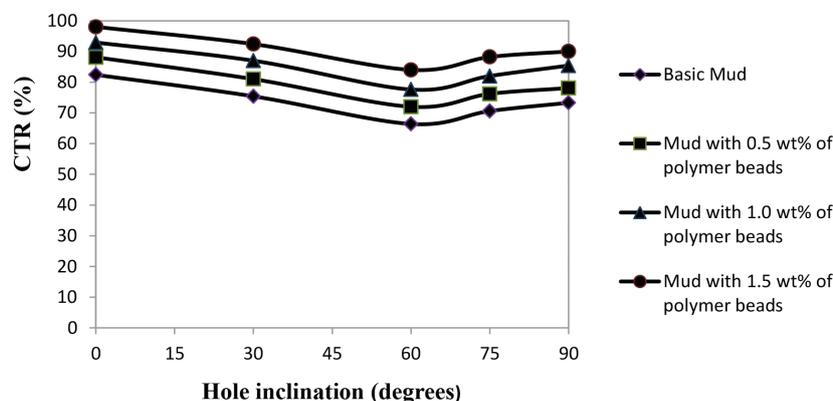


FIGURE 3. Cuttings transport performance for respective muds

RESULTS AND DISCUSSION

EFFECT OF POLYPROPYLENE BEADS

Considering only 0.5 wt.% concentration of polypropylene beads in the basic water-based mud prepared, it can be seen from Figure 3 that the cuttings transport ratio (CTR) was 88% as compared to that of basic water-based mud of 82% for the vertical position (i.e. 0°) of the test section. Moving further at the respective hole inclination angles investigated, mud with polypropylene beads was also observed to have performed better in cuttings lifting than that of the basic water-based mud. This outstanding performance has shown that if polypropylene beads were to be commingled with drilling fluid in any drilling operations, it would enhance the cuttings transport and invariably improve the effectiveness of the wellbore cleaning by the transporting fluid. The improvement recorded by the drilling mud with polypropylene beads has been influenced by two major forces that act on slipping cuttings of imperfect sphere in a turbulent flow, namely the gravitational and drag forces (Clark & Bickham 1994; Duan et al. 2007; Skalle 2011).

Generally, the presence of the polypropylene beads in the water-based mud has successfully reduced the slipping velocity of the drilled cuttings due to its buoyancy in the mud, which consequently reduces the Reynolds number of the particles and as such, if the Reynolds number of the slipping particles is reduced, invariably the coefficient of drag would increase (Skalle 2011). If the coefficient of drag is increased, a higher drag force would be experienced in the transporting fluid and thereby enhancing the cuttings carrying capacity of the mud for a better wellbore cleaning in vertical, deviated and horizontal conditions of the hole.

EFFECT OF INCREASE IN POLYPROPYLENE BEADS CONCENTRATIONS

Figure 4 shows that increasing the weight concentrations of the polypropylene beads resultantly increased the

cuttings transport performance of the mud by more than 10% (i.e. cuttings transport ratio of 98% at 1.5 wt.% of polypropylene beads as compared to 87% at 0.5 wt.% in a vertical hole). Furthermore, Figure 5 shows the cuttings transport ratio comparison for the incremental changes in the weight concentrations of polypropylene beads used. It was observed that at 75° inclination angle of the test section, all the various incremental changes in the concentrations of the polypropylene beads were found to have transported the drilled cuttings at an average incremental rate of 7% as can be seen at the intersection of the three curves.

EFFECT OF HOLE INCLINATION ANGLE

The cuttings transport ratio was found to have decreased (Figure 3) when the wellbore was deviated from the vertical to the near vertical plane (i.e. 0°-30°). This was inferred to have caused by a high impact of gravity acting on the sliding bed which led to the increase in cuttings concentrations on the lower end of the annulus. At this

juncture, it is pertinent to say that this research work has demonstrated credence and the observed critical angle at 60° is in consonant with that observed by Binzanti et al. (2003), Brown et al. (1989), Ford et al. (1990), Ogunride & Dosunmu (2012), Ozbayoglu et al. (2008), Peden et al. (1990), Sifferman & Becker (1992) and Tomren et al. (1986).

Dramatically, the declining performance of the transporting fluid reversed gradually as the hole inclination angle was changed from the near horizontal to the horizontal plane (75°-90°). This was due to the cuttings bed being less moveable as the impact of gravity was less felt. Figure 4 shows that inclination angle of 60° had the lowest cuttings transport ratio, followed progressively by 75°, 90°, 30° and finally 0° (vertical).

Though hole inclination angle impacted significantly on the cuttings transport performance of the drilling mud, but the presence of polypropylene beads has demonstrated a leverage in improving the cuttings carrying capacity of the water-based mud in spite of the enormous challenges imposed by hole angles.

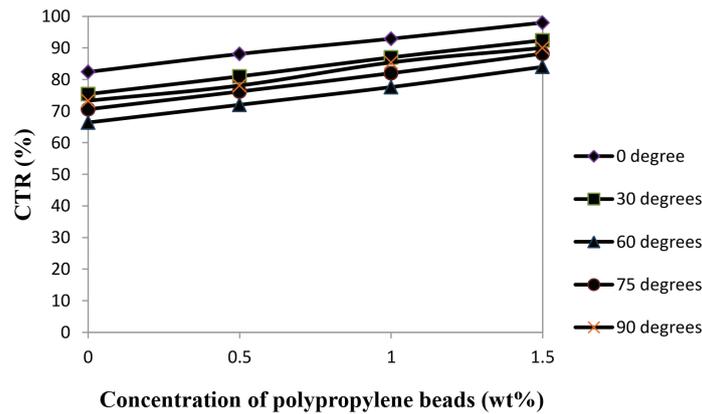


FIGURE 4. Cuttings transport ratio against weight concentration of polypropylene beads in the water-based mud

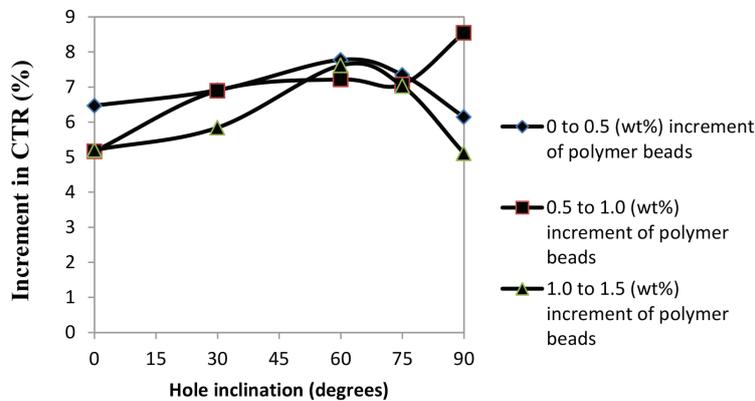


FIGURE 5. Incremental cuttings transport ratio against incremental changes in wt. % of polypropylene beads

CONCLUSION

The experimental parameters were borne of simulating for feasible field values and that used by other investigators. Commingling polypropylene beads with water-based mud has improved the cuttings transport performance of the said mud, Increasing the weight concentrations of the polypropylene beads would improve the cuttings transport performance of the said mud. Though hole inclination angle has a significant impact on cuttings transport in deviated wells, but mud with varying weight concentrations of polypropylene beads has fared well in the hole angles investigated as compared to that of basic mud, which shows that commingling polypropylene beads with the mud would offer better wellbore cleaning in drilling highly deviated or horizontal wells. The polypropylene beads being an inert and non-toxic material is environmentally friendly and could be washed, stored, and re-used for subsequent drilling operations, thereby cutting down overhead cost and improving the contractor's economic value.

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