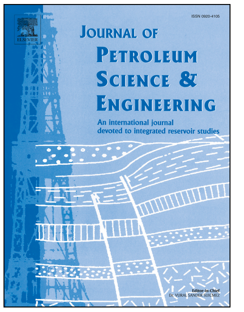
Accepted Manuscript



Performance of polyethylene and polypropylene beads towards drill cuttings transportation in horizontal wellbore

Hadyan Hakim, Allan Katende, Farad Sagala, Issham Ismail, Hussein Nsamba

PII: S0920-4105(18)30087-1

DOI: 10.1016/j.petrol.2018.01.075

Reference: PETROL 4662

To appear in: *Journal of Petroleum Science and Engineering*

Received Date: 8 June 2017

Revised Date: 26 January 2018

Accepted Date: 30 January 2018

Please cite this article as: Hakim, H., Katende, A., Sagala, F., Ismail, I., Nsamba, H., Performance of polyethylene and polypropylene beads towards drill cuttings transportation in horizontal wellbore, *Journal of Petroleum Science and Engineering* (2018), doi: 10.1016/j.petrol.2018.01.075.

Performance of Polyethylene and Polypropylene Beads towards Drill Cuttings Transportation in Horizontal Wellbore

Hadyan Hakim[1], Allan Katende[2,*] , Farad Sagala[3], Issham Ismail[1] and Hussein Nsamba[4] .
[1]Department of Petroleum Engineering and Renewable Energy, Universiti Teknologi Malaysia (UTM), [2]Department of Geoscience and Petroleum, Norwegian University of Science and Technology (NTNU), [3]Department of Chemical and Petroleum Engineering, University of Calgary (UC), [4]Department of Chemistry, Makerere University (MUK)

Abstract

Drilled cuttings removal is critical in drilling operations, especially in horizontal wells. These cuttings are postulated to be among the possible causes of many costly complications, such as mechanical pipe sticking, bore hole instability, drag and torque. This study proposes a new approach that uses polymer beads as a mud additive to improve cutting transportation. In this study, the effect of the concentration of polyethylene (PE) and polypropylene (PP) polymer beads on cuttings transport efficiency (CTE) in water-based mud in a horizontal wellbore was investigated. Experiments were conducted in a lab-scale flow loop equipped with a 13-ft (3.96 m) test section consisting of a concentric annulus acrylic outer casing (2 in. ID) and a static inner PVC drill string (0.79 in. OD). A total of 150 tests were conducted using 10 ppg water based mud (WBM) with 1% – 5% by vol. Concentrations of polymer beads (PE and PP) were added at a range of 8-9.5 cp. Six different sizes of drilled cuttings ranging from 0.5 to 4.0 mm were used as samples to determine the CTE at a constant 0.69 m/s average annular fluid velocity. The results revealed that CTE increased with the increase of polymer bead concentrations and that PP is better compared to PE overall due to its low density. The highest CTE was recorded at a 5% concentration of water-based mud polypropylene (WBMPP), which is approximately 96% for cutting sizes of 0.50mm–0.99mm.

Key Words.

Drilled Cuttings , Drilling Mud, Water-Based Mud, Polymer Beads, Polyethylene Beads, Polypropylene Beads.

I. Introduction

DRILLING is one of the most important jump-start in any oil and gas industry. This stage has been characterized as being very challenging, risky and necessitating extremely high capital investment. In addition, pipe stacking which causes poor wellbore cleaning is also experienced, Costa et al , (2008) predicts that this challenge will continue despite good industry practices. Yu et al (2004) further assert that an immediate remedy is required to avert this problem which increases operational costs and drilling time as well as reduced quality of directional, horizontal, extended reach and multilateral oil and gas wells. Experiments conducted by Massie et al (1995) showed that approximately 70% of the time lost as a result of unexpected events was associated with stuck pipe. Additionally, Hopkins & Leicksenring (1995), presented that one-third of the problems of stuck pipe were due to inadequate hole cleaning. The movement or transportation of drilled cuttings during deviated and horizontal drilling is mainly influenced by the force of gravity. The solids tend to be transported with a lower velocity compared to fluids since solids are denser than fluids. This results in drilled cuttings depositing and building up at the bottom annulus space of the wellbore thus causing drilling problems. This deposition phenomenon is usually referred to as cuttings bed. A controversial debate on methods which optimize hole cleaning properties has recently evolved; Saasen et al., (2002). Onuoha et al, (2015) reported that water-based mud with PP beads increase more than 10% of CTE for small size drilled cuttings (1.0-1.2 mm). From this study the following questions were addressed; does PE perform better than PP in terms of cuttings transport efficiency? Is there any significant difference between PE and PP in the application drilling fluid for cuttings recovery? These questions thus form the basis of this study in effort to understand the effect of polymer concentration (PE and PP) towards cuttings transport efficiency.

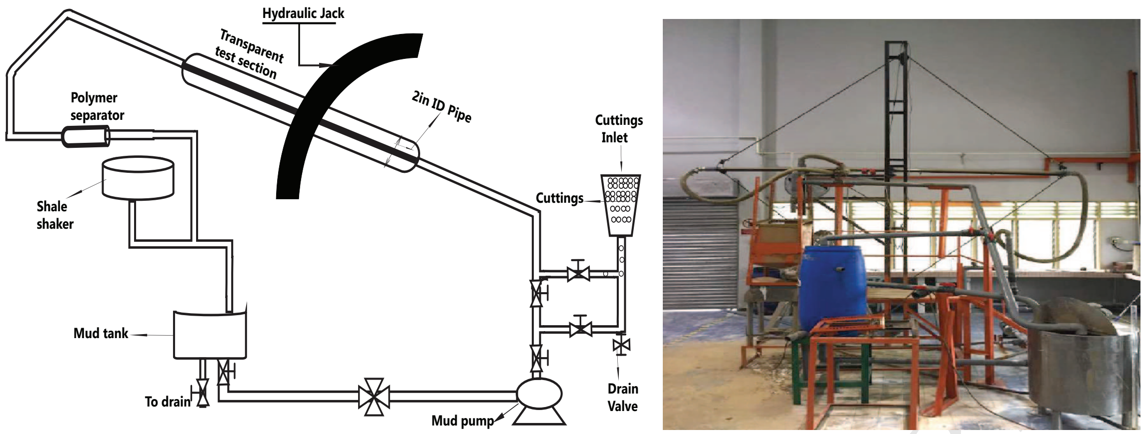
II. Experimental Set up and Methods.

A. Experimental Flow Loop

The experimental flow loop was designed to achieve the objective of this study, which was to investigate the performance of polyethylene and polypropylene beads in water-based muds on cuttings transport efficiency in a horizontal wellbore. The flow loop (Figure 1) was built with a concentric annulus test section of 13 ft (3.96 m) long acrylic pipe, with 2 inch ID that acted as a simulated wellbore/casing. The non-rotating inner drilled pipe was built with 0.79 inch PVC and sealed at both ends.

The annulus test section was set at 90^o throughout the experimental works. The mud was circulated using a 2-hp variable speed centrifugal pump with the capacity of about 200 liters mud tank installed connected to the pump. At the separation tank, there were two separation systems incorporated in the flow loop simulator to separate polymer beads (2 mm mesh container) and cuttings (200 μm wire mesh) respectively. The transported cuttings were collected after seven minutes of circulation process and six minutes of recirculation to clean up any cuttings residue inside the flow pipes before a new run can be made.

Received: June 8, 2017
Revised: January 26, 2018
*Corresponding Author: Allan Katende: ✉(allan_katende@hotmail.com)



(a) Schematic of the flow loop Rig Simulator (b) Lay out of the Flow Loop Rig Simulator.

Figure. 1: Flow Loop Rig Simulator.

B. *Preparation of Simulated Drill Cuttings*

In this study, six sized of cuttings were used as solid particles or simulated drilled cuttings as shown in Table 1. The sands were taken from Desaru Beach, Johor Bahru and its size was in the range between 0.50–4.00 mm with irregular in shapes. The density of sands was about 2.56 g/cc, which was determined using the standard (ASTM D4253-00, 2006) testing method.

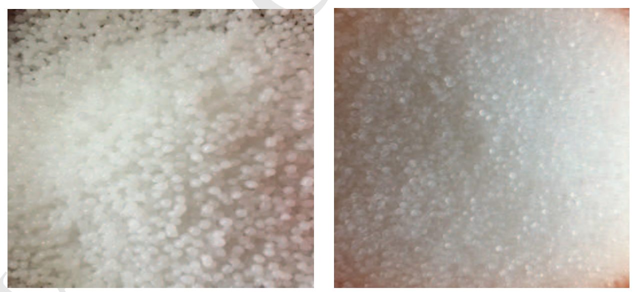
The preparation of the sand samples (simulated cuttings) started with cleaning it with tap water to ensure that no mud or other particles stuck around the sand particles. They were then sieved in a sieve shaker and dried in an oven.

TABLE 1: Simulated drilled cuttings size

Sand No	Size Diameter (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	2.80–4.00

C. *Polymer Beads*

Two types of polymer beads, namely, polyethylene and polypropylene beads, were used in this study, as shown in Figure 2. These polymer beads were added into the basic water-based mud respectively by percent volume in order to determine their effect on cuttings transport and to compare their performance on cuttings transport efficiency. Both types of polymer beads were sieved accordingly in the size range of 2.8-4.0 mm. The technical properties of both types of polymer beads are show in Table 2.



(a) Polyethylene beads (b) Polypropylene beads

Figure. 2: Types of polymer beads used in the study.

TABLE 2: Technical Properties of Polyethylene and Polypropylene beads

Properties	**Polyethylene**	**Polypropylene**
Relative density	1.14	1.01
Specific density	0.952	0.844
Shape	Spherical	Spherical
Melting point (^{o}C)	130.14	161.93
Colour	White	White (crystal like)

D. *Measurement Systems*

During the experimentation process, the following instruments were used for obtaining a good and reliable data acquisition and these include; ultrasonic flow meter, mud viscometer, low pressure low temperature filter press, mud balance, electronic weighting balance, electronic vernier calliper and a rheometer which was used to measure the rheological properties of the drilling fluids.

E. *Preparation of Drilling Fluids*

The preparation of drilling mud and the measurement of mud rheological properties were done according to American Petroleum Institute, (2009) recommended practices, before it was tested in the flow-loop rig simulator. The basic water-based mud (WBM) was prepared by mixing 15.0 g of bentonite

[2] http://www.scomigroup.com.my/GUI/pdf/drilling_fluid.pdf

(viscosities), 85.3 g of barite (weighting agent), 0.25 g of soda ash (pH control) and 1 g of starch into 350 ml of distilled water (continuous phase) based on the Scomi's[2] formulation. For the water-based mud with five different percentages of weight of polyethylene beads added, the similar mud formulation was used. However, the only thing that changes was the weight of barite added since the introduction of polymer beads has reduced the mixture of mud density due to its light weight i.e., less dense than water. The addition of barite has kept the density constant, which is 10 ppg. The resulted mud formulations and rheological properties for five different concentrations of polyethylene beads and polypropylene (based on % of volume) added were tabulated in Tables 3, 4, and 5 respectively.

TABLE 3: Basic WBM Rheological Properties

Rheological Properties	Value	Unit
Mud density	10	ppg
Apparent viscosity	11	cp
Plastic viscosity	8	cp
Yield point	4	$lb/100ft^2$
Gel strength @ 10 secs	5	$lb/100ft^2$
Gel strength @ 10 min	11	$lb/100ft^2$
pH	9	–

TABLE 4: Mud formulations for WBMPE

	Mud samples				
Components	1 % PE	2% PE	3% PE	4% PE	5% PE
Distilled water, ml	350.00	350.00	350.00	350.00	350.00
Bentonite, g	15.00	15.00	15.00	15.00	15.00
Soda ash, g	0.25	0.25	0.25	0.25	0.25
Starch, g	1.00	1.00	1.00	1.00	1.00
Initial mud weight, ppg	8.52	8.51	8.50	8.47	8.45
Barite, g	87.07	87.66	88.25	90.01	91.20
Polyethylene beads, g	3.33	6.66	9.99	13.32	16.65
Final mud weight, ppg	10.00	10.00	10.00	10.00	10.00

TABLE 5: Mud formulations for WBMPP

	Mud samples				
Components	1 % PP	2% PP	3% PP	4% PP	5% PP
Distilled water, ml	350.00	350.00	350.00	350.00	350.00
Bentonite, g	15.00	15.00	15.00	15.00	15.00
Soda ash, g	0.25	0.25	0.25	0.25	0.25
Starch, g	1.00	1.00	1.00	1.00	1.00
Initial mud weight, ppg	8.53	8.51	8.49	8.45	8.42
Barite, g	86.48	87.66	88.84	91.19	92.96
Polyethylene beads, g	2.95	5.91	8.86	11.82	14.77
Final mud weight, ppg	10.00	10.00	10.00	10.00	10.00

III. Results and Discussions

A. Rheological Model of Formulated Drilling Fluids

Figure 3 shows a graph of shear stress versus shear rate of all mud samples formulated. Based on the graph, all mud samples showed the characteristic of Herschel–Bulkley model[3]. This is because the trend lines or the shapes of the curves are similar and matched to the Herschel–Bulkley model.

Figure 4, shows that as the shear rate increases, the viscosity of mud samples decreases. This implies that all drilling fluids used behave like pseudo-plastic fluids, which are characterized as shear thinning, meaning they will have less viscosity with higher shear rates.

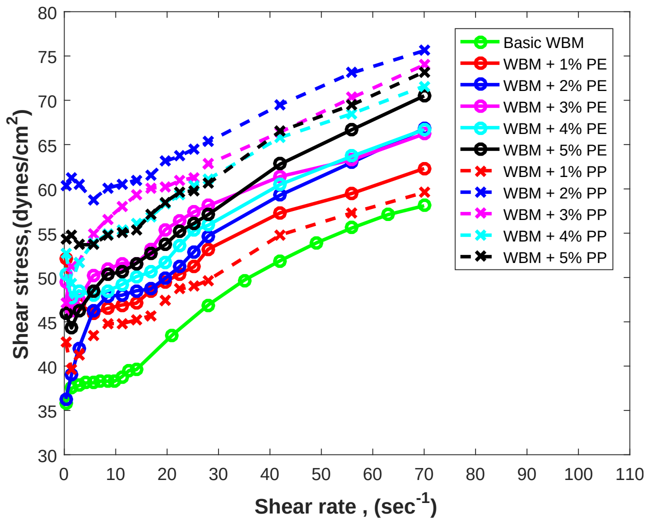


Figure. 3: Shear stress versus shear rate of all mud samples.

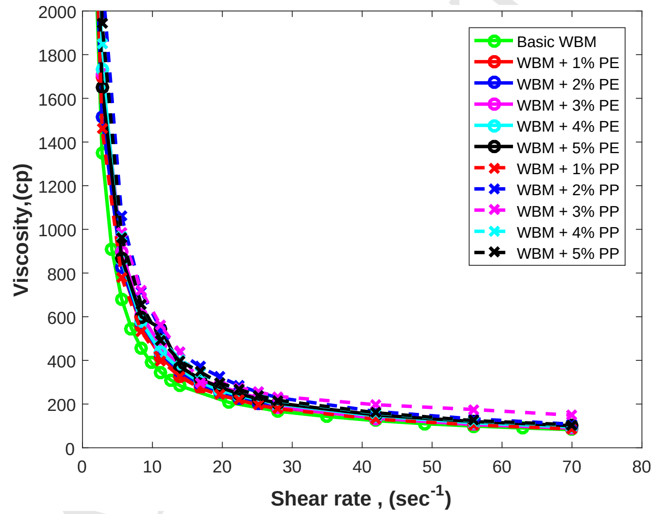


Figure. 4: Viscosity versus shear rate for all mud samples.

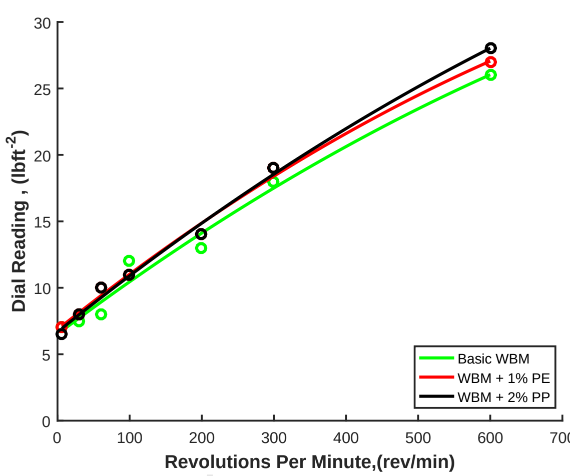


Figure. 5: Mud consistency curve for the three types of mud systems.

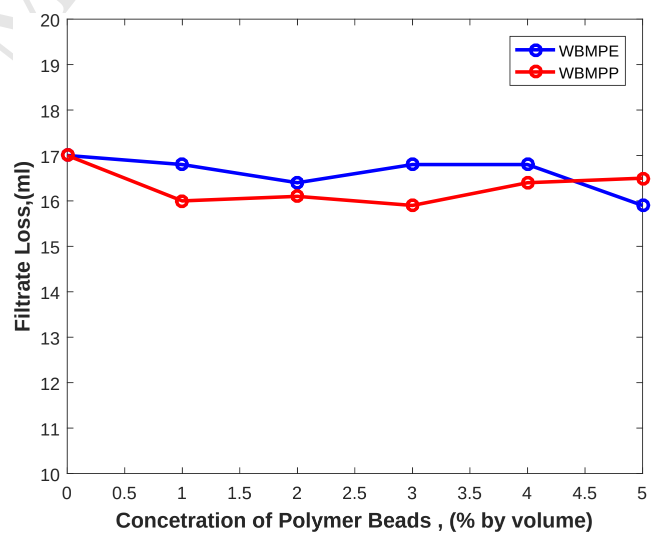


Figure. 6: Filtrate volume at 30 minutes for all mud samples.

B. Rheological Properties of Drilling Fluids

Rheological properties of drilling fluids were the key components to ensure that the specific type of mud could handle the wellbore needs during drilling operations. In this study, the basic water-based mud was added with different concentration of polymers, i.e., 1% to 5% polyethylene and polypropylene polymer beads.

When the base fluid of mud is added with some material such as polymer beads, the performance of rheological properties is expected to be slightly different than the basic water based mud. This study only focused on testing the drilling fluids at the ambient temperature and pressure, which means that the investigation after aging was not conducted. The summary of the results is tabulated in Table 6.

[3] The Herschel-Bulkley fluid is a generalized model of a non-Newtonian fluid.

TABLE 6: Rheological properties of all mud samples

Mud Samples	Apparent Viscosity (cp)	Plastic Viscosity (cp)	Yield Point ($lb/100ft^2$)	Initial Gel ($lb/100ft^2$)	Final Gel ($lb/100ft^2$)	pH
Basic WBM	11.0	8.0	6.0	5.0	13.0	9
WBMPE 1%	11.5	8.3	6.5	5.0	13.0	9
WBMPE 2%	12.1	8.5	7.3	6.0	14.0	9
WBMPE 3%	12.3	9.0	5.5	6.0	13.5	9
WBMPE 4%	11.8	9.0	6.5	5.5	14.5	9
WBMPE 5%	12.5	8.8	7.5	6.5	14.0	9
WBMPP 1%	13.3	9.0	8.5	7.5	15.5	9
WBMPP 2%	13.5	9.0	9.0	8.0	15.5	9
WBMPP 3%	13.5	9.3	9.0	8.5	16.0	9
WBMPP 4%	12.5	9.5	6.0	6.0	15.5	9
WBMPP 5%	12.3	9.0	7.5	7.5	14.5	9

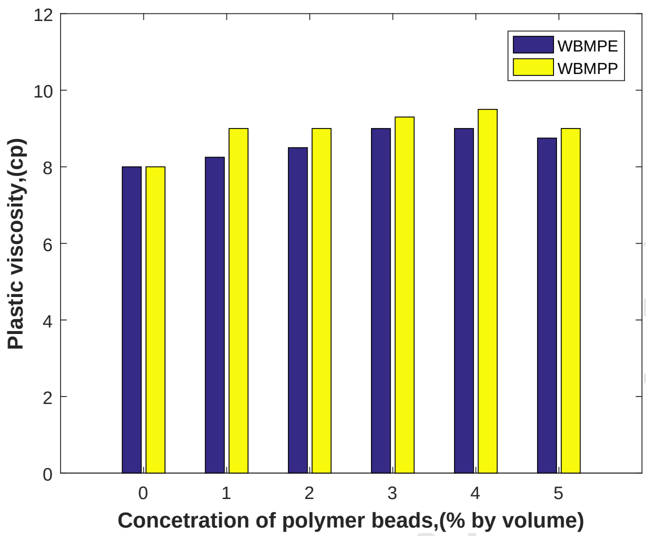


Figure. 7: Plastic viscosity versus concentration of polymer beads (Polyethylene and Polypropylene).

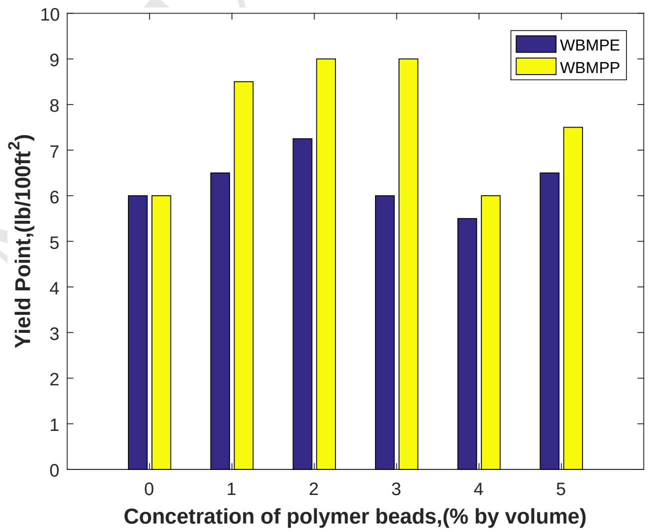


Figure. 8: Yield point versus concetration of polymer beads (Polyethylene and Polypropylene) added.

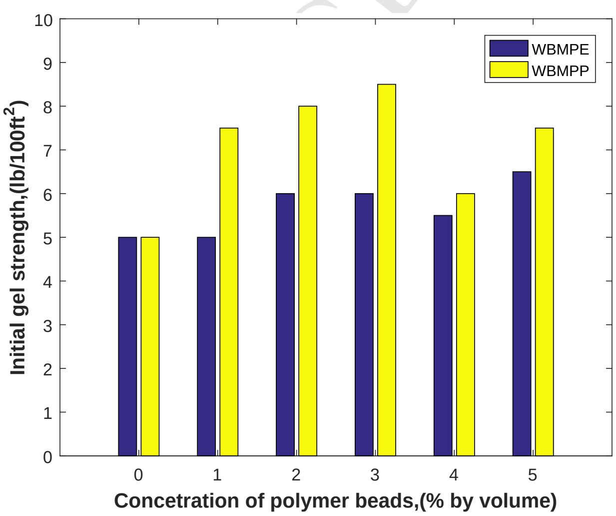


Figure. 9: 10 seconds gel strength of all mud samples.

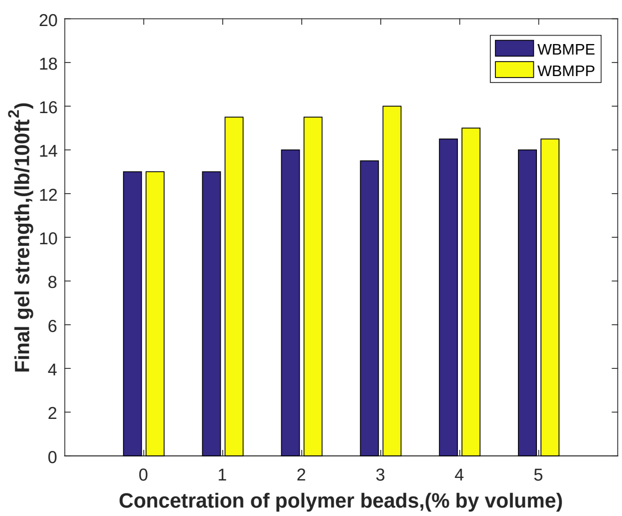


Figure. 10: 10 minutes gel strength of all mud samples.

B.1 Plastic Viscosity

Figure 7, shows that the plastic viscosity of basic WBM with both types of polymer beads has slightly increased at the range of 8 cp to 9.5 cp. After adding the polymer from 1% to 5% concentration (by volume), the plastic viscosity calculated shows a slightly increment in trend for all tests. This reflects that by adding the polymer beads, the plastic viscosity of mud has slightly increased since the polymer beads added act as solids and inert materials.

B.2 Yield Point

The yield point is the initial resistance to flow caused by electrochemical forces between the particles. Figure 8 shows that the yield points of the basic WBM with polymer beads for both PE and PP were are slightly increased. For example, the yield point of (WBM + 1% PE) has increased from 6 to 6.5 lb/100 ft^2. Also, the yield point of (WBM + 1% PP) has increased from 6 to 8.5 lb/100 ft^2.

B.3 Gel Strength

Gel strength signifies the ability of drilling fluids to suspend the cuttings at quiescent condition. In this study, the gel strength was measured at both 10-second and 10-minute. Gel strength at 10-second and 10-minute measured on viscometer, indicates the strength of attractive forces (gelation) in a drilling fluid under static conditions.

B.4 Filtrate Loss at Low Temperature Low Pressure (LTLP)

The filtrate loss was studied to indicate the ability of the mud to seal permeable or producing formation with low-permeability filter cake. Filtration loss takes place under two conditions, which are static and dynamic. In this study, the filtrate loss rate and thickness of the mud cake were measured under the static condition (at ambient temperature and at low pressure of 100 psi), where the mud is not being circulated and the filtrate volume and mud cake thickness increases with time.

Figure 6 shows that all muds seem to have similar filtrate losses, i.e, from range of 15 – 17 ml. In this case, the polymer beads used did not really show significant effect on reducing fluid loss potential of drilling fluids. Rather than the beads dispersed and floating around the mud as solid particles, and sometimes, it drops or sticks at the bottom of mud cake formed which might be affecting the inconsistency of fluid loss volume. However, the highest fluid loss volume is about 17 ml, which is from basic WBM. Table 7 and Table 8 show a summary of permeability of filter cake for basic WBM, WBMPE and WBMPP respectively.

TABLE 7: Summary of permeability of filter cake for Basic WBM and WBMPE.

Mud Properties	Mud Samples					
	Basic WBM	1% WBMPE	2% WBMPE	3% WBMPE	4% WBMPE	5% WBMPE
Cummulative filtrateloss, ml	17.0	16.8	16.4	16.8	16.8	15.9
Average filter cake thickness, mm	3.005	2.593	2.946	2.215	2.921	2.428
Permeability, mD	0.457	0.390	0.432	0.333	0.439	0.346

TABLE 8: Summary of permeability of filter cake for WBMPP.

Mud Properties	Mud Samples					
	Basic WBM	1% WBMPP	2% WBMPP	3% WBMPP	4% WBMPP	5% WBMPP
Cummulative filtrateloss, ml	17.0	16.0	16.1	15.9	16.4	16.5
Average filter cake thickness, mm	3.005	2.606	2.868	2.537	2.431	2.601
Permeability, mD	0.457	0.373	0.413	0.361	0.357	0.384

C. Effect of Polymer Beads towards CTE

From Figure 11, it can be seen that the recovery or cuttings transport efficiency (CTE) of the simulated drilled cuttings by considering 1% vol of polyethylene beads in the basic WBM prepared has increased from 84.3% to 88.2% as compared to that basic WBM alone for the Sand 1 (0.50-0.99 mm). As the concentration of polyethylene beads increases from 1% to 2%, the cutting transport efficiency increased to become 89.3% for cutting size of 0.50-0.99 mm. Moving further at the respective polymer beads concentration added, i.e., (3%, 4% and 5%), the performance of cuttings transportation was observed to perform better than that of the basic mud and the highest CTE for Sand 1 is about 92.5% for PE at 5% vol concentration. Furthermore, the similar phenomenon can be seen towards the addition of polypropylene beads concentration as shown in Figure 12. This outstanding performance has shown that if the polymer beads were to be applied with WBM in any drilling operations, it would be commingled with WBM and thus enhances the cutting transportation to the surface. Therefore, this will improve the effectiveness of the wellbore cleaning during drilling operation.

For the comparison of the performance between polyethylene and polypropylene, the results show that the performance of PE showed a better incremental at 1% and 2% vol. concentration of polymer used, especially for Sand 1 and Sand 2. However, as the concentration of polymer added increase at 3% to 5%, the performance of PP shows a better and competitive result for all cuttings sizes as compared to PE when comparing the trend curves side-by-side in the Figures 11 and 12. The overall results show that WBMPP has a better increment about 4% higher as compared to WBMPE. This is because the low density of PP will have greater up-thrust force during the circulation compared to higher density of PE, thus provide higher buoyant force during cuttings transportation.

D. Effect of Increase in Polymer Beads Concentration

Figures 11 and 12 show the graph cutting transport efficiency vs. polymer beads concentration added for polyethylene and polypropylene beads respectively. Obviously, the trend of the graph shows that when the concentration (by volume) of the polymer beads increases, it would resultantly increase the cuttings transport efficiency (CTE). The maximum concentration tested, which is at 5% by volume concentration of polymer beads was observed using smallest cutting size of 0.50-0.99 mm showing the most efficient cuttings removal performance of about 90% for mud with 5% PE and 96% for mud with 5% PP respectively compared to 1% of polymer beads (PE and PP), which show 55% (PE) and 63% (PP). By comparing with the basic WBM, the CTE was the lowest for all cuttings sizes without the addition of polymer beads. In fact, this also applied to all cuttings sizes that the highest concentration of polymer beads (5% vol.) used gave better recovery in overall. This demonstrates that the polymer beads have increased the CTE with the higher concentration of polymer beads produced better CTE compared to basic WBM.

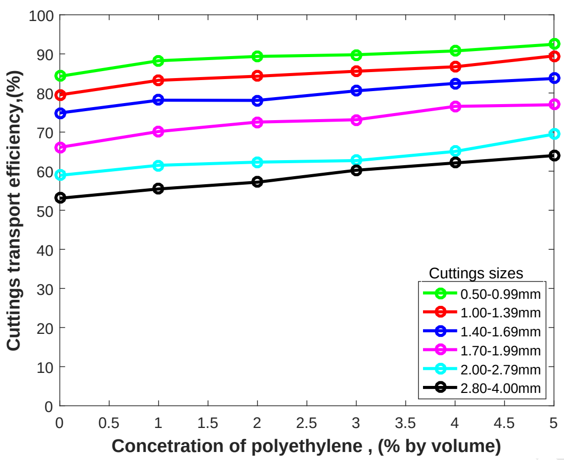


Figure. 11: Cuttings transport efficiency at different concentrations of PE.

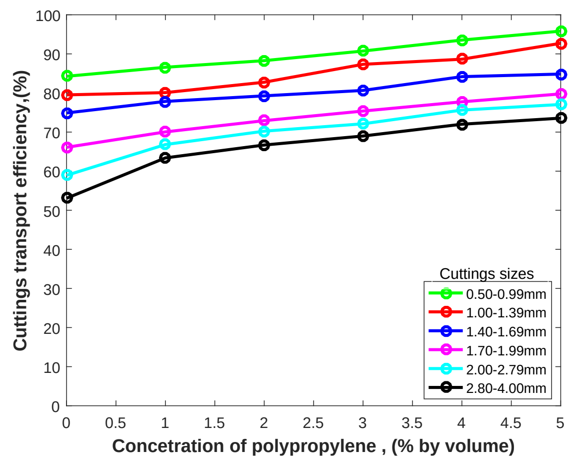


Figure. 12: Cutting transport efficiency at different concentrations of PP.

E. Effect of Cuttings Sizes

Figure 13 shows the recovery percentage of drilled cuttings against six different sizes of cuttings in the basic water-based mud (WBM). The results showed that the cuttings transport efficiency (CTE) has reduced for the horizontal angle as the size of drilled cuttings increase. For example, at 1% concentration of polyethylene added, the CTE for drilled cuttings size of 0.5-0.99 mm was about 88%. But it reduced to 83% as the drilled cuttings size increased to 1.00-1.39 mm. One can see that further increment of the cutting sizes, the CTE of the said mud used has reduced and the lowest CTE is for Sand 6, which is about 55%. The similar trend can be seen as the concentration of PP increased to 5% as shown in Figure 14. Mathematically, this is because as the diameter of the particle increases, this will cause the gravitational force that acts on each cutting particle to be greater. Therefore, the higher force of gravity influenced the larger size of cuttings. This can be seen at 5 % of PE with the cutting size of 2.80 4.0 mm, the CTE was only about 65%, which is the lowest recovery for 5% PE used.

For the justification behind this result, which displays that as the cuttings sizes increase, the cuttings transport efficiency (CTE) has decreased. The reason is because the drilled cuttings are transported mainly by rolling motion at high deviated wellbore, Skalle (2011). According to Skalle (2011), the rolling of particles commences when the rolling torque resulting from the drag and lift force is able to overcome the counteracting torque from gravity and cohesion force. So, the bigger particles will have higher impact on the settling of the drilled cuttings along the bed due to its greater gravitational force. This implies that the bigger cuttings sizes tend to settle along the bedside easily as well as it will have slower rolling motion compared to smaller sizes of drilled cuttings due to higher frictional force with the wall. This condition usually occurs before the cuttings bed development. After cuttings bed builds up, in terms of annulus cuttings concentration, the smaller cuttings are hardly to be transported compared to larger cuttings size as reported by; Duan et al. (2006), Gavignet et al (1989), Subhash et al (2000) and Yu et al (2004).

The experiment also correlates with the observation by; Peden et al (1990) as they observed that smaller cuttings are easier to transport in terms of MTV. Furthermore, Peden, et al. (1990) also concluded that smaller cuttings are easier to transport at all angles of inclination in an annulus pipe when pipe rotation is not present. So, it is confident to say that this experiment was valid since the flow loop used did not have inner pipe rotation. Empirically, the hole cleaning in horizontal wellbore can be classified with respect to cuttings bed behavior. Based on mass, momentum and energy balance, bed behavior is to a large part determined by particle size; Skalle (2011). Therefore, decrease in cutting size leads to increase in shear area available to move the cutting along the wellbore efficiently. That is why in rotary drilling operation, the pipe rotation helps to crush the larger cuttings into smaller ones, thereby enhancing the cuttings transport during drilling operation, Skalle (2011).

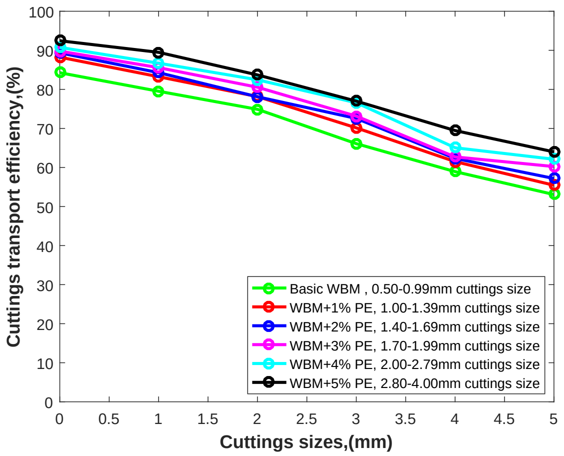


Figure. 13: Cuttings transport efficiency for WBMPE on different cuttings sizes.

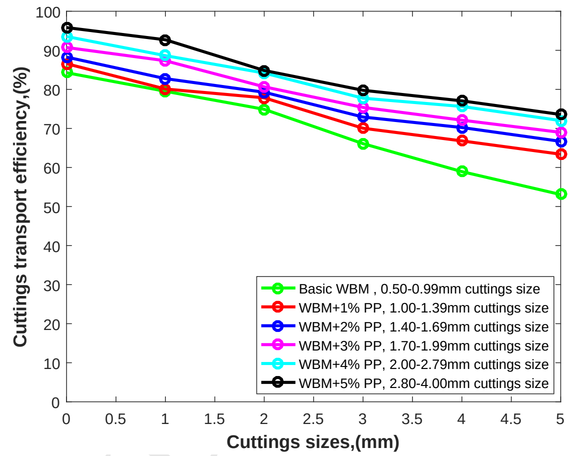


Figure. 14: Cuttings transport efficiency for WBMPP on different cuttings sizes.

IV. Conclusions

The application of polymer beads in water-based mud improved the cuttings transporting efficiency due to the effect of buoyant force. Increasing the concentration of the polymer beads (PP and PE) drastically improved the cutting transport efficiency of the drilling mud. The results showed that CTE increased with the increment of polymer beads concentration and PP is better compared to PE in overall due to its low density. The highest CTE was recorded at 5% concentration WBMPP which is about 96% for cuttings size 0.50-0.99 mm and this actually had improved by more than 10% CTE increment for all cuttings size compared to basic mud. In terms of drilled cuttings size effect, the smallest cuttings were found to be the easiest to transport compared to larger sizes. In summery the application of polymer beads in drilling mud had commingled with the said mud thus improving cuttings transport in horizontal wellbore.

V. Competing Interests.

The authors declare no competing financial interests

VI. Nomenclature

PP	Polypropylene
PE	Polyethylene
ID	Inner Diameter
MTV	Minimum Transport Velocity
CTE	Cuttings Transport Efficiency
WBM	Water Based Mud
WBMPP	Water Based Mud Polypropylene
WBMPE	Water Based Mud Polyethylene
PVC	Polyvinyl Chloride
LTLP	Low Temperature Low Pressure

References

[1] American Petroleum Institute. (2009). *Recommended Practice for Field Testing Water-based Drilling Fluid API-RP-13B-1. Fourth Edition Dallas: American Petroleum Institute.*

[2] ASTM D4253-00. (2006), *Standard Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table, ASTM International, West Conshohocken, PA. doi: 10.1520/D4253-00R06.*,

[3] Azar, J. J. and Sanchez, R. A. (1997), *Important Issues in Cuttings Transport for Drilling Directional Wells.* SPE 39020 https://doi.org/10.2118/39020-MS

[4] Azouz, I., Shirazi, S. A., Pilehvari, A. (1993) , *Numerical Simulation of Laminar Flow of Yield-Power-Law Fluids in Conduits of Arbitrary Cross-Section.* http://fluidsengineering.asmedigitalcollection.asme.org/article.aspx?articleid=1427636

[5] Becker, T. E., Azar, J. J.,and Okrajni, S. S. (1991) , *Correlations of Mud Rheological Properties with Cuttings-Transport Performance in Directional Drilling.* SPE-19535-PA.https://doi.org/10.2118/19535-PA

[6] Bilgesu, H. I., Ali, M. W., Aminian, K., and Ameri, S. (2002)., *Computational Fluid Dynamics (CFD) as a Tool to Study Cuttings Transport in Wellbores.* SPE-78716-MS.https://doi.org/10.2118/78716-MS

[7] Bilgesu, H. I., Mishra, N., Ameri, S. (2007)., *Computational Fluid Dynamics (Understanding the Effects of Drilling Parameters on Hole Cleaning in Horizontal and Deviated Wellbores Using Computational Fluid Dynamics.* SPE-111208-MS.https://doi.org/10.2118/111208-MS

[8] Brown, N. P., Bern, P. A., and Weaver, A. (1989)., *Computational Fluid Dynamics (Cleaning Deviated Holes: New Experimental and Theoretical Studies,.* SPE-18636-MS. https://doi.org/10.2118/18636-MS

[9] Cho, H., Subhash, N., and Samuel, O. (2000)., *Computational Fluid Dynamics – A Three-Segment Hydraulic Model for Cuttings Transport in Horizontal and Deviated Wells.* SPE-65488-MS. https://doi.org/10.2118/65488-MS

[10] Clark, R. K. and Bickham, K. L. (1994), *A Mechanistic Model for Cuttings Transport.* SPE-28306-MS. https://doi.org/10.2118/28306-MS

[11] Costa, S. S., Sergio, A. B., Martins, A. L. (2008), *Simulation of Transient Cuttings Transportation and ECD in Wellbore Drilling.* SPE-113893-MS. https://doi.org/10.2118/113893-MS

[12] Hussaini, S. M. and Azar, J. J. (1983)., *Experimental Study of Drilled Cuttings Transport Using Common Drilling Muds.* SPE-10674-PA. https://doi.org/10.2118/10674-PA

[13] Jalukar, L. and Azar, J. J. (1996)., *Extensive Study on Hole Size Effect on Cuttings Transport in Directional Well Drilling.* ASME Fluids Engineering Conference and Exhibition. July 1996. San Diego, California.

[14] Larsen, T. I., Pilehvari, A. A., and Azar, J. J. (1997)., *Development of a New CuttingsTransport Model for High-Angle Wellbores Including Horizontal Wells.* SPE-25872-PA. https://doi.org/10.2118/25872-PA

[15] Piroozian, A., Ismail, I., Yaacob, Z., Babakhani, P., and Ismail, A. S. I. (2012). , *Impact of Drilling Fluid Viscosity, Velocity and Hole Inclination on Cuttings Transport in Horizontal and Highly Deviated Wells.* https://link.springer.com/article/10.1007/s13202-012-0031-0

[16] Peden, J. M., Ford, J. T., and Oyeneyin, M. B. (1990). , *Comprehensive Experimental Investigation of Drilled Cuttings Transport in Inclined Wells Including the Effects of Rotation and Eccentricity.* SPE-20925-MS. https://doi.org/10.2118/20925-MS

[17] Skalle, P. (2011). , *Drilling Fluid Engineering. Venturs Publishing Aps ISBN 978–87–7681–929–3.* http://bookboon.com/en/drilling-fluid-engineering-ebook

[18] Taghipour, A., Lund, B., Sandvold, I., Opedal, N., Carlsen, I., Vralstad, T., Ytrehus, J. D., Skalle, P., and Saasen, A. (2012). , *Experimental Study of Rheological Properties of Model Drilling Fluids.* https://nrs.blob.core.windows.net/pdfs/nrspdf-f0c6cec0-2df4-4aa7-b2ed-4aa06c84dc7e.pdf

[19] Wang, K., Yan, T., Sun, X., Shao, S., and Luan, S. (2013). , *Review and Analysis of Cuttings Transport in Complex Structural Wells.* http://dx.doi.org/10.2174/1876973X20130610001

[20] Williams, C. E. Jr. and Bruce, G. H. (1951), *Carrying Capacity of Drilling Muds.* https://doi.org/10.2118/951111-G

[21] Yan, T., Wang, K., Sun, X., and Luan, S. (2014), *State-of-the-Art Hole-Cleaning Techniques in Complex Structure Wells.* https://doi.org/10.2174/18722121086661402250029 50

[22] Yu, M., Melcher, D., Takach, N., Miska, S. Z., and Ahmed, R. (2004)., *A New Approach to Improve Cuttings Transport in Horizontal and Inclined Wells.* SPE-90529-MS. https://doi.org/10.2118/90529-MS

[23] Alain A. Gavignet and J. Sobey (1989)., *Model Aids Cuttings Transport Prediction.* SPE-15417-PA. https://doi.org/10.2118/15417-PA

[24] Onuoha, M., Ismail, I., Piroozian, A., Mamat, N., & Ismail, A. (2015)., , *Improving the cuttings transport performance of water-based mud through the use of polypropylene beads.*,Sains Malaysiana, 44(4), 629-634. http://journalarticle.ukm.my/8642/

[25] Ozbayoglu, M. E., Miska, S. Z., Reed, T.,& Takach, N. (2004). , *Analysis of the Effects of Major Drilling Parameters on Cuttings Transport Efficiency for High-Angle Wells in Coiled Tubing Drilling Operations.* SPE-89334-MS https://doi.org/10.2118/89334-MS

[26] Duan, M., Miska, S. Z., Yu, M., Takach, N. E., Ahmed, R. M., and Zettner, C. M. (2006). , *Transport of Small Cuttings in Extended Reach Drilling.* SPE-104192-PA https://doi.org/10.2118/104192-PA

[27] Massie, G.W. ; Castle-Smith, J. ; Lee, J.W. ; Ramsey, M.S. (1995). , *Amoco's training initiative reduces wellsite drilling problems.* PETROLEUM ENGINEER, 67, no. 3, (1995): 48

[28] C.J. Hopkins (NAM) and R.A. Leicksenring (NAM) (1995). , *Reducing the Risk of Stuck Pipe in The Netherlands.* SPE-29422-MS https://doi.org/10.2118/29422-MS

[29] Saasen, A. and Loklingholm, G. (2002). , *The Effect of Drilling Fluid Rheological Properties on Hole Cleaning.* SPE-74558-MS https://doi.org/10.2118/74558-MS

Highlights

- Polymer beads as mud additives were studied for improving the transportation of drill cuttings in water-based mud.
- Polyethylene (PE) and polypropylene (PP) polymer beads increased the cuttings transport efficiency (CTE) when used in water-based mud.
- CTE increased with the increase of polymer bead concentrations for the two types of polymer beads used.
- Overall, polypropylene beads performed better compared to polyethylene beads due their low density.
- CTE was remarkably improved by the addition of polymer beads.