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Microbeads as Lubricant in Drilling Muds Using a Modified Lubricity Tester

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Abstract

Particles like barite and cuttings influence the friction properties of a mud. The standard API lubricity tester, however, cannot measure friction of fluids containing particles, and to overcome this problem it was modified with a cam setup. It was found that particles indeed alter the friction.

Large beads are being used to reduce friction. They are, however, filtered out in the solids control equipment and to avoid this, we have investigated smaller polymer microbeads which will pass unhindered. The microbeads reduce the friction in water based muds with around 40% which is significantly better than four commercial lubricants.

Introduction

Mechanical friction during drilling operations is a problem in long narrow, highly inclined boreholes. Aston *et al.*[1] presents an excellent discussion on causes of and cures for high friction. Some of the cures include application of oil or pseudo oil based mud and lubricants. Use of oil and pseudo oil based muds are highly restricted because of environmental concerns. Even adding small amounts of oil-based lubricants to water based muds raise questions. Consequently, the value of finding an improved environmentally friendly friction reducer applicable in water based mud is high.

Traditionally, friction reducers can be divided into two types: liquids and solid particles. Liquids form a film between the two surfaces minimising any contact and consequently also the friction. However, their efficiency depend heavily on mud type and may also be reduced when used together with other types of mud additives.[2] When used in high-solids muds the efficiency is reduced, sometimes no friction reduction is found at all.[3,4] Liquid additives include among others glycol-, oil-, ester-, and fatty acid ester-based lubricants. Particles, on the other hand, do not depend as much on mud type. One solid lubricant is treated graphite powder where the graphite have a lamellar structure whose planes are coupled by weak van der Waal bonds. When exposed to tension, these layers part and thus reduce the friction.

Lammons[5] developed and used glass beads in mud which was said to act as small ball bearings downhole. Round, incompressible particles are imbedded in the wall cake and provide a load-bearing surface between pipe and wall. The beads may create a small standoff distance for pressure communication and flow as well. This standoff and point contact may reduce the overall frictional surface area. Coarse beads (400-800 µm) are used for spotting. Most beads will be retained in the wall cake when circulation is re-established while those remaining in the mud will be removed by most shaker screens. Fine beads (44-88 µm) will pass most shaker screens but are removed by desilters. Kuchkov *et al.*[6] reported the use of ellipsoidal glass beads. Ellipsoidal glass particles increased the contact area of these anti-frictional particles, and thereby decrease their ability to penetrate deep in the filter cake. Aston *et al.*[1] found that 75 µm glass beads reduced the friction with up to 68% whereas 600 µm beads were crushed.

Brookey *et al.*[7] introduced copolymer beads (260-550 µm) as a solid lubricant. The incentive to use these beads were the same as for glass beads; to form slippery layers between the borehole and the drill string. Field application of the beads can vary from spotting small pills of beads in specific sections of the borehole to carrying some concentration of beads in the system while using a bead recovery unit (recovery is necessary due to high bead price). They claimed a reduction was observed in the field, but no specific values were given. The plastic bead results of Aston *et al.*[1] will be discussed below.

The solution suggested in this paper is to use microsized spherical monosized polymer beads which will pass the solids control equipment unhindered. But measuring the friction properties of particles with existing laboratory equipment is difficult, so before the beads are introduced, we will discuss how this problem was solved.

Modified Lubricity Tester

The standard API/Baroid lubricity tester[8] is widely used for estimating the friction between drillstring and wellbore, and for finding how different drilling muds and lubricants alter the friction.

However, this setup does not allow particles to enter between the block and rotating ring which is a serious limitation considering that drilling muds do include particles like barite and cuttings. Apparatuses to overcome this deficiency has been presented by Bol[3] and Aston *et al.*,[1] both using a smaller drillstring inside a larger casing which allow particles to wedge themselves between the two surfaces. These setups are quite elaborate and to simplify collection of friction data, we used the standard API tester[8] as a starting point. This was modified with a cam arrangement which lifts the block away from the rotating ring allowing particles to enter between the two faces, and thus measuring the friction properties of particles in a fluid. The principle of the modification is shown in **Fig. 1** where the cam and cam follower are placed underneath the ring and block.

Adjustment of the maximum opening gap between ring and block is done with two screws behind the cam follower. Measurement of the gap is done with the caliper arrangement outlined in **Fig. 2**. The caliper was calibrated by placing thin sheets of brass foil with differing thickness between the block and ring, and the corresponding movement of the caliper was recorded. For correct gap adjustment the procedure is reversed: the cam is rotated until maximum lift is obtained, the caliper is read, and if not correct, adjusted by the two screws.

Optimal gap opening depends on the particles used; large particles needs a larger gap than smaller particles. **Fig. 3** shows the recorded friction for four gap openings using 24-30 μm beads. A gap of 100 μm is obviously too small whereas the apparent friction increase at 400 μm probably is explained by the extra energy needed to lift the cam. We have used a gap of 250 μm for all tests.

Some further modifications had to be carried out for optimal use of the tester. The first was to replace the fixed position of the torque wrench arm. When the cam is lifting, the only part of the system to give is the spring in the torque wrench arm itself, and as this is very stiff, even a small cam lift increased the torque with up to 200%. This in turn increased the power needed to rotate the ring during cam opening, resulting in an uneven rotational speed. The problem was solved by replacing the holding clamp of the torque wrench arm by suspending the end of the arm with a soft coil spring. This reduced the torque increase during cam lift down to 10-20%. For the same reason and to reduce wear, a torque of 50 lbf-in. was used instead of the recommended 150 lbf-in. Even then, some deposits of dirt were found on the ring where the block touched the ring after cam action. This was removed by using successively finer abrasive sheets, the last one polishing the ring. To avoid any uneven wear on the ring, the cam was rotated periodically relative to the ring.

The second enhancement was to replace the block support edge with a ball (see Fig. 1). The ball is placed centrally behind the block curvature. This was necessary for increasing the freedom of movement, as some unstable readings were experienced without it. An additional advantage of the ball is that adjustment of the eccentric shaft is not critical. On a few occasions, the block adhered to the ring during cam action which was solved by placing two magnets behind the block on each side of the ball. A few other aspects of the tester were investigated as well. Torque readout drift was found to be small, and any drift was noted and corrected for. The temperature increase (because of friction) during a five minute test was small, only 1-2°C (1.8-3.6°F).

The electronics inside the tester were modified to allow a voltage output of the torque reading. This output was connected to a personal computer with a data acquisition card making a reading every second during a test. The friction factors reported in this paper are an average taken over the last minute of the test which normally lasted for 5 or 10 minutes.

Apart from the modifications described above, the standard API procedure was followed.

But how do the results from the modified tester compare with those of the standard tester? The difference of friction coefficients in some fluids are shown in **Table 1**. Except for the water based mud, there is an increase in the recorded friction factor caused by extra energy needed for cam lifting action. This small increase, however, is conservative and no correction is applied for it. Decreased friction in the water based mud is caused by particles already in the mud.

We have also tried to estimate the accuracy of the tester as shown in **Table 2** with a typical error of ±4%. This conclusion is based on all our tests, some of which are shown in **Table 3**. The total error is divided into three sources: The first is the torque read-out which includes the electronics inside the tester and data acquisition by a PC. The second error source, adjustment of the torque arm, is exacerbated because we use a torque of 50 lbf-in. and this equals only 7 mm (0.28 in.) on the torque scale. To investigate, the torque was varied between 25 and 100 lbf-in. in five steps and a line was fitted to the results, estimating a typical error to be ±2%. In addition, drift of the readout introduced some small error, and other unknown factors may also contribute. An example of repeatability and stableness of the modified tester is presented in **Fig. 4**.

Microbeads

Spherical monosized polymer beads have been applied to reduce friction during pulling of long cables inside plastic tubes. In this specific application, the beads functioned as a ball bearing. And as mentioned above, large polymer beads are already available commercially for use as friction reducers in drilling muds. They have been used with good effect for running casing but application during drilling is problematic: they are filtered out in the solids control equipment because of their relatively large size. These experiences, however, do show that beads are able to reduce friction.

We have used spherical monosized polymer beads as a model system to investigate how and if smaller beads can be used in drilling muds. **Figs. 5 and 6** show bead no. 3 mixed in a weighed mud and HEC solution. The method for producing the beads[9] makes it simple to vary parameters like size, degree of crosslinking (hardness, compressibility) and polymer material (wettability, thermal stability, density). The importance of size is self-evident as the beads need to be less than around 70 µm to avoid being filtered out. A high degree of crosslinking will produce brittle beads and a low value will give elastic and sticky beads, none of which is wanted. It was estimated that 20-50% crosslinking would be ideal. Wettability may decide if the beads will stick to for example metal, while temperature stability is essential for surviving high downhole temperatures. The bead density should be in the same range as for drilling muds.

Most of the monosized beads were made of polystyrene (PS) crosslinked with divinylbenzene (DVB). This material is temperature stable, and pore size distribution, degree of crosslinking and copolymerization with other monomers are easy to control. The density is around 1.06 g/cm^3. The properties of the produced beads are shown in **Table 4** where both size (7-70 µm) and degree of crosslinking (5-60%) were varied systematically. One bead type made of polyvinylchloride[10] (PVC) was tested as well (density 1.4 g/cm^3). Both materials are chemically stable, i.e., there should be no environmental concerns.

To investigate the effect of surface charge and hydrophobic properties, i.e. steel affinity and wettability, three different strategies like soaking of particles in esters and oil, adsorption of copolymers and chemical modification of particle surface were tried out. It was reasoned that these modifications would reduce the friction even further by making the beads more likely to be close to or in contact with the drillstring. The modifications are listed in **Table 5**.

The chemical modification of beads was done by reaction in sulfuric acid to introduce sulfonic acid groups on the bead surface. The sulfonic groups will ensure free particles in the mud (hydrophilic). Modification by adsorption of different copolymers were also carried out. These copolymers are very small tentacles (length 3-200 nm) on the bead surface which change the degree of hydrophilicity. Several copolymers were tested and contact angle was used as a measure of hydrophobic properties. Attempts to "soak" particles in commercial lubricants, such as ester- and fatty acid ester-based lubricants were also tried.

The beads do not influence mud properties, except a negligible increase in viscosity and a very slight decrease in 10 minute gel. And in theory, the beads should also reduce wear, as they, and not drillstring, casing, or formation, should take the majority of the wear.

But do the beads work as a ball bearing or do they slide? It has been suggested in the literature that they act as ball bearings. Initially we thought that this was true, but a simple calculation indicated that they slide. To confirm this estimate, the block was replaced with a curved piece of PVC which reduced the (sliding) friction to somewhat below that of the PVC beads, i.e., the microbeads slide.

Results and Discussion

Initial tests revealed that particles like barite and cuttings alter the friction of a drilling mud. To simulate shale cuttings, bentonite was hydrated in distilled water at 0.5 to 2 vol% concentration causing a friction increase around 35% as shown in **Fig. 7**. Barite, which is used as a density material in most drilling muds, reduced the friction by up to 25% using 1 to 6 vol% in an unweighed commercial water based mud (see **Fig. 8**). Bol[3] and Aston *et al.*[1] also found a reduction when adding barite to unweighed muds. These results underline the importance of the modified lubricity tester; the standard tester will often produce misleading results. This deficiency may explain the discrepancies between laboratory results and field experience for other lubricants.

The beads in Table 4 were tested in a 1 wt% hydroxyethyl-cellulose (HEC) solution to avoid distortion from other particles like barite. First the size was investigated while the degree of crosslinking was held constant at 40%. We found that when using bead no. 5 (7 µm) a concentration of at least 4 vol% was necessary to reduce the friction down to around 0.15, whereas 1 vol% was enough for larger beads; consequently the bead size should at least be 21 µm. Then bead size was held constant at 28 µm while degree of crosslinking ranged between 5 and 60%. It was found that crosslinking did not alter the friction significantly. The results also showed that increasing the concentration above 1 vol% did not lead to any further significant reduction.

Next, the most promising beads were tested in a commercial water based field mud (1.44 g/cm^3; 12.0 lbm/gal) to see if the beads would reduce friction in a mud containing barite. The results are shown in **Table 6** and **Fig. 9**. They are not as clear as the results for the HEC-solution. In the field mud it seems that crosslinking does play a role; a low degree of crosslinking is beneficial. This may be explained by interaction between beads and other particles, where softer beads (with less crosslinking) are more easily plastically deformed to absorb any oncoming particle. The best beads (1, 3, 13, and 14) reduced the friction from 0.20 down to 0.11-0.13. This is a significant reduction. The commercial lubricants, on the other hand, only reduced the friction down to 0.15-0.18. The exception is the 200-600 µm beads, which due to their size will be filtered out in the shale shaker and therefore are of less interest. For comparison, Aston *et al.*[1] reported that 250 µm plastic beads reduced the friction between 30 and 60% using different muds and test conditions. They also found that for sieved plastic beads less than 106 µm a concentration of at least 1.4 vol% was necessary for any significant friction reduction (up to 50%) and that friction increased with higher loads.

In order to reduce the friction even more, as discussed above, the surface properties of the most promising beads were modified, but as Table 3 and **Fig. 10** show, no significant friction reduction was observed.

Some other aspects were investigated as well. Beads with a large size distribution are less expensive to produce, and to test how this influence friction, 28 and 50 µm beads were mixed in equal volume concentrations. Compared to the two beads tested separately, **Fig. 11** shows that largest bead contribute most to the reduction. Thus, for a steel to steel surface, a shallow size distribution is preferable whereas the opposite may be true in the open hole where the borehole wall is rough and different sized beads will fill the corresponding "holes" in the wall.

The results so far are very promising, but they should be followed up with tests to assure that the beads can withstand the harsh downhole conditions. These should include compressive strength, temperature, and long term tests, and in the end, followed by field tests.

Conclusion

All drilling muds contain particles which will influence the friction properties of the mud. To allow friction measurement of fluids containing particles, the standard API lubricity tester was modified with a cam arrangement to allow particles to enter between block and ring. Barite and bentonite was found to alter the friction and consequently, the standard tester will often produce misleading results. This deficiency may explain the discrepancies between laboratory results and field experience.

Several microsized polymer beads have been tested in the modified tester where a 1 vol% concentration was found to be sufficient. The best beads reduced the friction factor in a water based mud from around 0.20 down to 0.11-0.13. This is significantly better than four commercial lubricants (0.15-0.18).

Acknowledgement

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SI Metric Conversion Factors

°F	(°F–32)/1.8	= °C
g/cm^3	× 1.0*	E+03 = kg/m^3
in.	× 2.54*	E+01 = mm
lbf-in.	× 1.129 848	E–01 = N·m
lbm/ft^3	× 1.601 846	E+01 = kg/m^3
lbm/gal	× 1.198 264	E+02 = kg/m^3
micron	× 1.0*	E+00 = µm
mL	× 1.0*	E+00 = cm^3
nm	× 1.0*	E–09 = m
ppb	× 2.853 010	E+00 = kg/m^3
psi	× 6.894 757	E–03 = MPa

*Conversion factor is exact.

Table 1–Difference between standard and modified lubricity tester.

Fluid	Standard tester	Modified tester
Distilled water, test no. 1	0.286	0.292
Distilled water, test no. 2	0.303	0.310
Distilled water, test no. 3	0.305	0.307
Distilled water, test no. 4	0.297	0.307
Exxsol D 60, 50 lbf-in.	0.170	0.181
Exxsol D 60, 100 lbf-in.	0.154	0.167
Paraffin oil, 50 lbf-in.	0.004	0.015
Paraffin oil, 100 lbf-in.	0.008	0.017
Water based mud, test no. 1	0.201	0.189
Water based mud, test no. 2	0.201	0.186
Water based mud + 1 wt% treated graphite powder	0.194	0.180

Table 2–Estimated uncertainty of modified tester.

Cause	Typical (%)	Maximum (%)
Torque read-out	±1	±2
Torque setting	±2	±5
Other	±1	±3
Total	±4	±10

Table 3–Friction coefficients with 1 vol% bead concentration in an unweighed water based mud.

Test no.	Mud	B-03*	B-16	B-17	B-18	B-14	B-19	B-20
1	0.216	0.137	0.139	0.144	0.142	0.175	0.172	0.162
2	0.215	0.126	0.126	0.135	0.136	0.170	0.168	0.165
3	0.209	0.129	0.121	0.134	0.131	0.171	0.176	0.174
4	0.219							
Average	0.215	0.131	0.129	0.138	0.136	0.172	0.172	0.167
% red.**		39	40	36	37	20	20	22
St.dev.	0.004	0.006	0.009	0.006	0.006	0.003	0.004	0.006
% dev.***	2.3	4.2	6.9	3.6	4.0	1.4	2.3	3.6

*Bead number.
**% reduction compared to unweighed mud without beads.
***% difference between maximum and minimum measured values divided by two.

Table 4–Description of the tested beads.

Bead	Base material	Size (μm)	% cross-linking
B-01	PS/DVB*	50	5
B-02	PS/DVB	25	8
B-03	PVC**	24-30	0
B-05	PS/DVB	7	40
B-06	PS/DVB	21	40
B-07	PS/DVB	28	40
B-08	PS/DVB	70	40
B-09	PS/DVB	56	40
B-10	PS/DVB	42	40
B-11	PS/DVB	28	60
B-12	PS/DVB	28	20
B-13	PS/DVB	28	5
B-14	PS/DVB	28	8
B-15	PS/DVB	7	5

*Polystyrene crosslinked with divinylbenzene
**Polyvinylchloride

Table 5–Modified beads.

Bead	Bead + Modification
B-16	B-03 + Copolymer
B-17	B-03 + Fatty acid ester no. 1
B-18	B-03 + Ester
B-19	B-14 + Sulfonated
B-20	B-14 + Copolymer

Table 6–Friction of beads and commercial lubricants in a water based field mud. The friction of the mud is 0.20.

Lubricant	Concentration (wt%) 1	2
Treated graphite powder	0.175	0.175
Fatty acid ester no. 2	0.170	0.155
Beads 200-600 μm	0.127	0.137
Ester	0.161	0.153
B-01	0.127	0.134
B-03	0.137	0.109
B-07	0.210	0.185
B-08	0.171	0.161
B-09	0.159	0.148
B-13	0.134	0.128
B-14	0.125	0.113
B-15	0.186	0.158

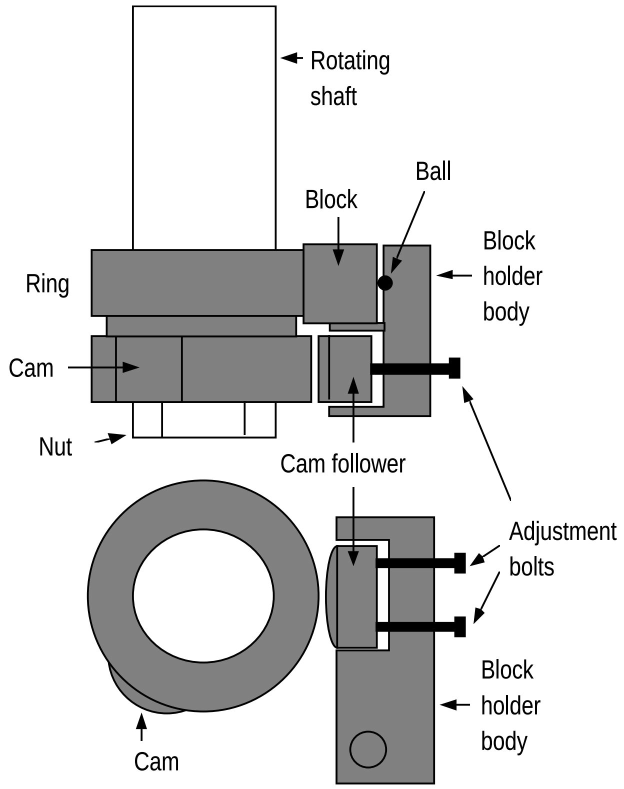

Fig. 1–Principle of the cam arrangement for the modified lubricity tester. Side view at the top and cross sectional view at the bottom.

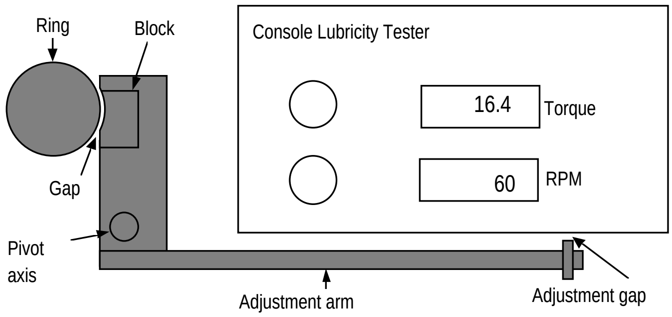

Fig. 2–Caliper setup for adjusting the gap between block and ring.

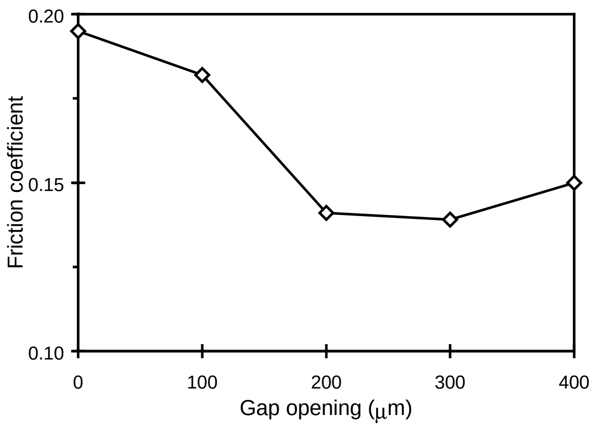

Fig. 3–Optimal gap opening for 24-30 μm beads (B-03) in a weighed water based mud.

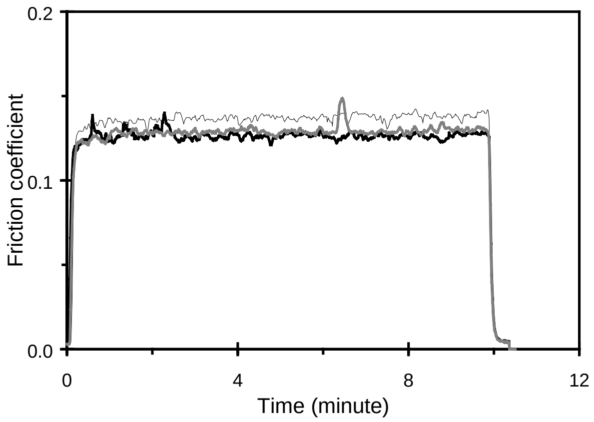

Fig. 4–Three tests with 1 vol% bead B-03 in an unweighed water based mud.

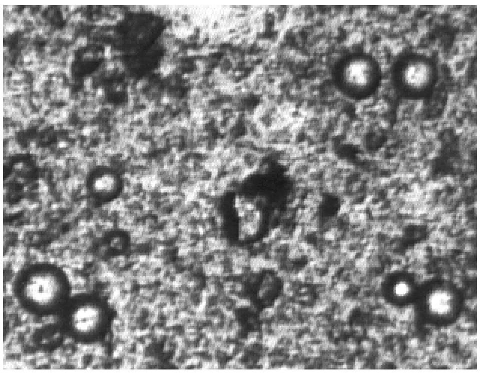

Fig. 5–Microscope photograph of 24-30 μm beads (B-03) in a barite weighed mud (magnification ca. 175×).

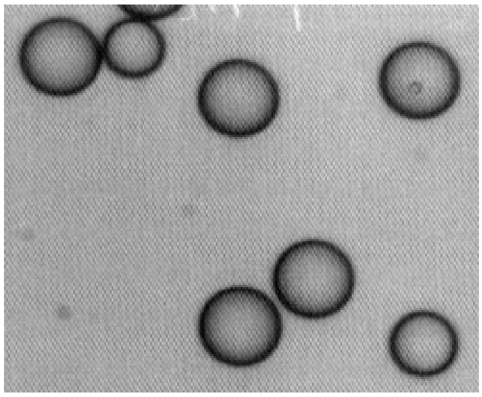

Fig. 6–Microscope photograph of 24-30 μm beads (B-03) in HEC (magnification ca. 350×).

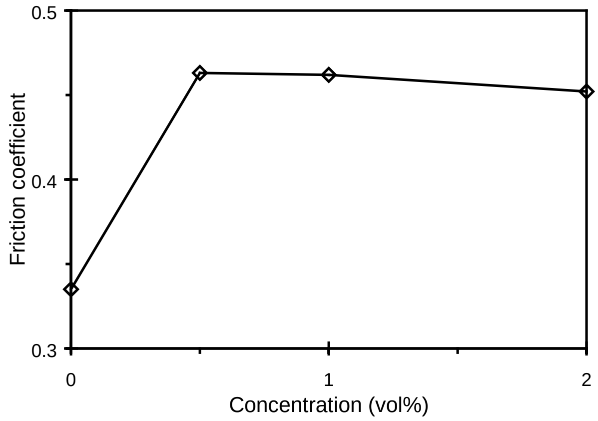

Fig. 7–Effect of adding bentonite to distilled water.

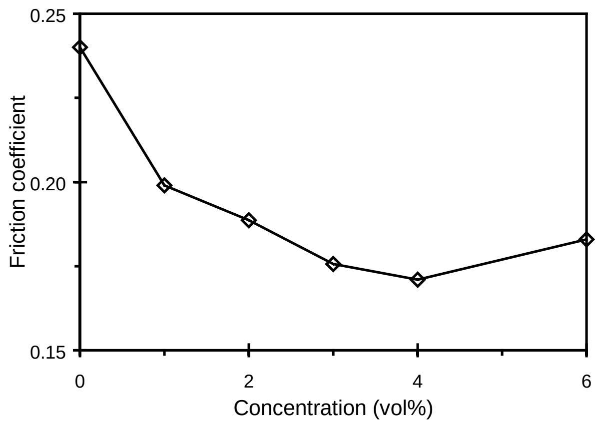

Fig. 8–Effect of adding barite to an unweighed water based mud.

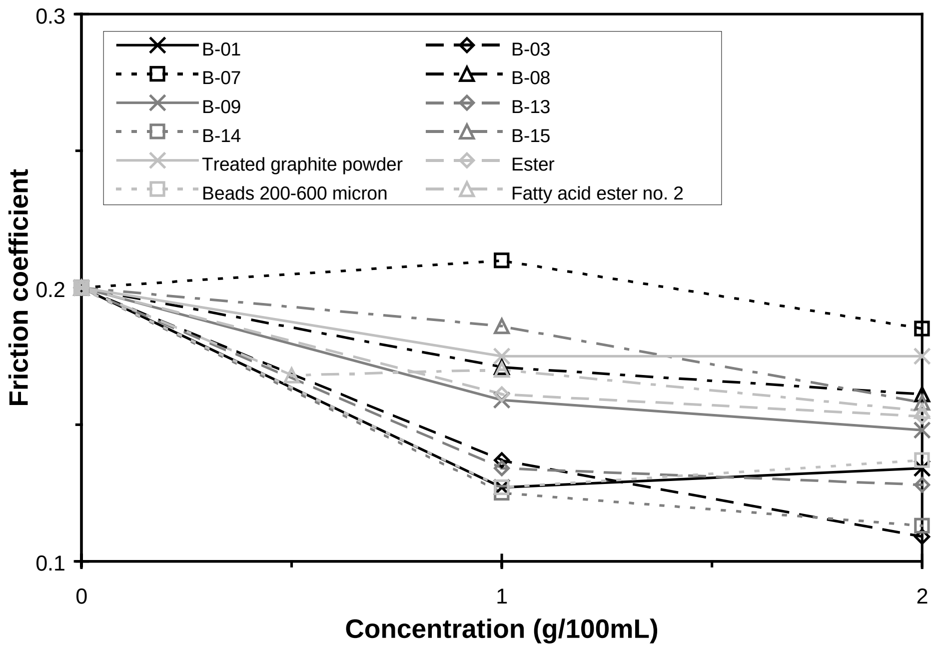

Fig. 9–Friction results for unmodified beads and commercial lubricants in a weighed water based mud.

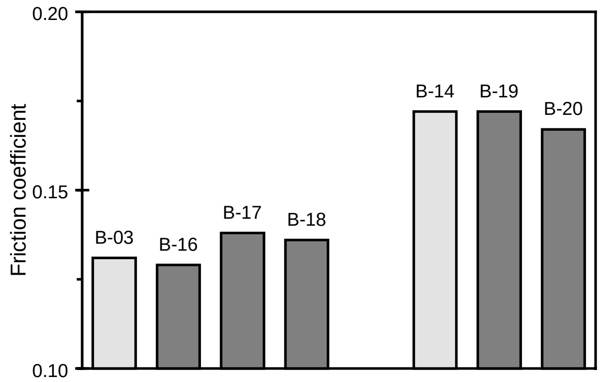

Fig. 10–Friction of the modified beads (dark grey) compared to unmodified beads (light grey).

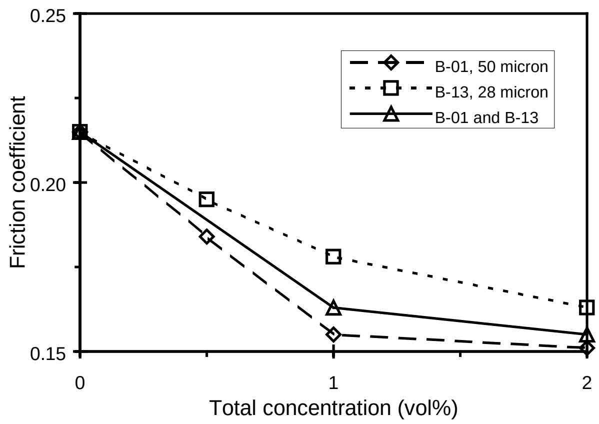

Fig. 11–Effect of mixing two bead sizes.