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Drilling Waste Slurries: Minimizing Slurry Volume and Improving Slurry Stability During Transfer

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Abstract

Transfer of waste generated during the drilling process is taking greater importance as environmental legislation reduces, and in some cases prohibits, disposal of cuttings to the seabed. Slurrification of the cuttings into a material suitable for pumping and transfer has become one of the solutions to moving and storing cuttings. Oil-based cuttings slurries can be re-injected on-site but this is not always applicable. Therefore the slurry may need to be transported to allow disposal or injection into a dedicated well.

Slurrification of cuttings generally increases the volume of the waste by a factor up to 4. This additional volume creates some handling problems. Increased storage space on board the transport vessel will be required, turn-around time will be increased and waste spillage becomes more likely. Another disadvantage will be longer cleanup times of the vessels. Technology has been developed to reduce the slurry-dilution ratio whilst still providing a stable and pumpable slurry. This allows cuttings slurrification to be considered as an economically viable method of cuttings transfer.

Chemical treatments have been investigated and designed for oil-based cuttings to decrease slurry viscosity and allow slurry transfer with conventional equipment. This decrease in viscosity will allow an increased concentration of cuttings to slurrified while retaining pumpability. The chemical treatment also increases slurry stability during storage and transportation. Vibration and rocking motions, simulating boat movements, were deemed critical factors in the stability of slurries during transportation.

This paper presents the analysis of oil-based cuttings slurries prepared at different solids concentrations and discusses the effect of vibration and rocking motions on slurry stability. The effect of different chemical treatments in terms of reducing slurry settling during transportation is also discussed.

Introduction

Drilling waste generated during offshore operations has to be disposed in a safe and cost-effective manner. Bulk slurry transfer represents one alternative for managing cuttings when they are transferred to a centralized injection or disposal facility. The advantages of this system over conventional skip-and-ship systems (where cuttings boxes are used to transfer the cuttings between sites) vary depending on factors such as rig space availability, storage capacity and distance of rig from dedicated injection well or disposal site. The main advantages are in general reduced cost, reduced waste volume from cleaning containers, and reduced logistical difficulties at the rig-site.

In order to minimize the waste generated and to allow the cuttings slurries to be transported effectively, the slurries have to be thin enough to be pumped using standard systems, yet stable enough to prevent cuttings settlement during transportation. Previous studies[1] have shown that slurries can be treated chemically in order to minimize the dilution ratio yet obtain a low-viscosity slurry. The next phase was to determine the stability of these slurries during static (storage) and dynamic (transportation) conditions.

Weather conditions, especially in the North Sea area, induce severe boat movement. The main movements inducing settling in solid-liquid suspensions are the pitch and roll of the boat. Another factor to be considered is the vibration induced by boat engines. All these factors can have a direct or indirect effect on slurry stability during transportation.

The results reported and discussed in this paper cover the effect of boat movements on slurry stability. Methods have been developed in order to simulate the rocking movements and vibrations on board transport vessels. This paper also presents data on chemical treatments used to stabilize slurry properties during transport.

Background Information

The settling of particles in non-Newtonian fluids has previously been studied.[2] The settling potential of particles in a fluid can be predicted from knowledge of the slurry composition. The shapes of the particles and the particle density have an effect on their settling potential,[3] but the main factor is the viscosity of the suspension.

We can assume that the settling during transit of the slurrified cuttings particles resembles the sag of barite in drilling and other mud-related operations. For such systems, static sag (in unsheared muds) is inversely proportional to Yield Point (YP), so that a large YP is effective in minimizing static sag.[4] Experiments have also shown[4] that dynamic sag at a shear rate, γ, is inversely proportional to the effective viscosity, η_e, at that shear rate, where η_e = (shear stress at shear rate γ)$\div\gamma$. Thus,

$$\text{dynamic sag} \propto \frac{1}{\eta_e} \qquad (1)$$

For the Bingham model of rheology assumed herein, the effective viscosity is

$$\eta_e/\text{cP} = \frac{511}{\gamma/\text{s}^{-1}} \times YP/(lb/100\,ft^2) + PV/\text{cP} \qquad (2)$$

If γ is small, e.g. a few s^1, as expected for a slurry subject to the motion of a boat, the dominant part of the rheology will be YP, and for the slurries,

$$\text{dynamic sag} \propto \frac{\gamma}{YP} \qquad (3)$$

Thus, in order to minimize settling during transit, γ should be kept as small as possible and a large YP is advantageous. Plastic Viscosity (PV) plays little part in controlling the dynamic settling.

Experimental methods

Slurry Preparation

Slurries mixed using field cuttings were prepared in 600-mL quantities by adding the required weight of cuttings to a Waring blender and then pouring in the correct weight of seawater. If chemical treatment was required, it was also added at this time. The mixture was blended at low speed, 50 Hz for 5 minutes. Mixing time was kept constant between each test in order to be able to compare the results.

Rocking Table

A rocking table was used to simulate the boat rocking. The speed and the angle can be varied. After speaking with boat builders and boat users, the parameters for boat rocking were set as follows:

- 15 – 20° angle
- 8-s periodicity

This corresponds to a strong storm in the North Sea. These parameters were found to be quite representative to weather conditions worldwide and would give us a worst-case scenario.

The rocking table design is presented in Fig. 1. Up to 3 containers could be tested simultaneously and the slurry volume was kept at 500 mL. Slurries were rocked for 16 hours, after which density measurement of the top, middle and bottom layers was taken. The degree of solids settling was determined by measuring the SG of these layers. The SG was determined by filling a syringe with a known volume of slurry and determining the weight change of the syringe. The SG was calculated as the (weight increase)/(volume of slurry). Using these SG measurements, the sag factor for each slurry was calculated using the formula :

$$Sag\ Factor = \frac{\rho\ bottom}{\rho\ bottom + \rho\ top} \qquad (4)$$

A sag factor of 0.5 would indicate that there was no solids settling. A sag factor of >0.5 would indicate that the bottom layer has a higher SG than the top. This would suggest that on a boat under the same conditions, the slurry would have a tendency to settle and thus cause problems with slurry pumping and tank cleaning. The repeatability of this method was very good and gave a standard deviation of ± 0.03.

Vibrating Table

The typical vibration from boat motors is around 10 Hz with an amplitude of 0.2 to 0.3 mm. The first approach was to use a sieve shaker. After some preliminary tests, it was decided to use a vibration of much higher frequency than what boat tanks are subjected to and an alternative vibration table was constructed. A diagram of this set up is given in Fig. 2. The vibrating table consisted of 2 steel plates joined by 4 low frequency mounts. On top of this was placed two rocking tables separated by a vibrator and an accelerometer.

The vibrator causes the accelerometer shaft to move up and down. The accelerometer terminals were connected to a multimeter (AC voltmeter) and the voltage measured. The voltage can theoretically be correlated to frequency of vibration. The vibrator was attached to a dimmer switch that should have given control over the frequency of the vibrations. However, when the dimmer switch was low the vibrator would stop. It was thus decided for consistency to use the dimmer switch at maximum, which gave ± 300 mV on the multimeter. As no correlation between voltage and vibration frequency has been ascertained for this experimental set-up and as the amplitude of vibration cannot be measured at this stage, the test protocol using this table was used to compare the performance of different slurries rather than a true representation of the boat vibration effect.

The amplitude of vibration varies depending on the load placed upon the table. The vibration transmission to each container was tested using 4 containers filled with 500 mL of tap water. It was seen that the degree of water movement depended on the positioning of the plastic container on the rocking tables. It was concluded that in order to get similar vibration on 2 containers, the boats should contain 500 mL of slurry and be placed on separate rocking tables diagonally opposite each other. This is illustrated in Fig. 3. Four containers of similar weight could be tested at one time.

This set up also has the advantage over the sieve shaker of allowing the simultaneous testing of the effects of rocking and vibration.

Tests were run for 16 hours and settling potential calculated as mentioned in the section above.

Results

General

Cuttings received from North Sea operations were used for all these tests. Characterization of these cuttings was performed and is summarized in Table 1. Slurries were mixed at different cuttings ratios with the protocol described above. Slurry viscosity was characterized using a coaxial-cylinder viscometer. The resulting dial readings were recorded and plastic viscosity and yield stress were calculated.

Increasing the solids loading increased the yield point drastically. The PV, which characterizes slurry pumpabillity is quite low for all the slurries and fairly constant. Both yield point and plastic viscosity have an effect on slurry rheology and pumpability.

An increase in the solids concentration of the slurry will increase the interaction between particles and increase the YP. This increase in yield point will decrease the pumpability of the slurry. In this study, we are trying to minimize waste generated by increasing the solids concentration in the slurry. As can be seen in Fig. 4, this is not achievable as the slurry viscosity increases drastically with the solids loading and chemical treatment is therefore required to achieve this goal.

Slurry viscosity

Chemicals were tested to determine their ability to reduce yield stress. The results are summarized in Fig. 5. Reduction in yield stress was achieved with all the chemicals but some chemicals performed better than others. Increases in solids loading increased slurry viscosity but pumpable slurries were achieved with 1% v/v chemical treatment (Chemical A and Chemical B) and up to 40% v/v solids.

Rocking Table

Some of the additives, which performed the best during the viscosity tests, were evaluated under rocking and the solids concentration was varied. The slurries were subjected to 16 hours rocking as per the method described above and the sag factor calculated.[4] Results are summarized in Fig. 6. From these tests, it can be seen that rocking does induce some settling and changes in the slurry homogeneity, but the changes are not severe as the sag factor for most of these tests is below 0.540.

Under rocking conditions, chemical treatment stabilizes slurry properties and more homogeneity in the slurry was observed.

At 30% v/v solids loading, chemical treatment (Chemical A, C and D) stabilizes the slurry and the sag factor determined was lower than the base slurry with no chemical treatment.

At 35% v/v solids loading, good slurry stability and viscosity reduction were achieved with all the chemical treatments.

Fig. 7 illustrates the correlation between the yield stress and the sag factor. The lower the YP, the higher the sag factor. Slurry stabilization induced by chemical treatment can be observed as the viscosity of the slurry decreased and the sag factor also decreased compared to the base slurry. A minimum YP of 60 lb/100 ft^2 is required to achieve a pumpable and stable slurry at both 30% and 35% v/v solids concentration.

Vibration

Fig. 8 shows the effect of vibration and of both vibration and rocking on slurry stability with and without chemical treatment. In all cases the sag factor measured under vibration alone was lower than that when vibration was combined with rocking. With all slurries, the sag factor under vibration was close to 0.5, which means that very little stratification of the slurries was present. Even when the rheology of the slurry was low (*i.e.*, Chemical E treatment) little settling of the slurry was observed under vibration alone.

Slurries tested over 16 hours rocking and rocking and vibration were observed. Stratification of particles in a middle layer can be seen under rocking conditions and is represented in Fig. 9 but nothing was visible under vibration alone. The slurry appeared to be uniformly gelled throughout the sample with no solids settlement or compaction at the bottom of the container. Vibration doesn't seem to have a deleterious effect on slurry stability.

Same chemical treatments were applied to the slurry at 30% v/v cuttings concentration and were submitted to rocking and vibration. Fig. 10 presents the comparison between rocking alone and rocking plus vibrating in order to study the effect of both phenomena. The addition of chemical treatment at 1% v/v to the 30% v/v cuttings slurry causes a decrease in rheology compared to the base slurry but slurries treated with chemicals A, C and D have been stabilized to rocking and to rocking and vibration, as the sag factor has been reduced.

For most of the slurries, there is little difference in the sag factor observed under vibration and rocking as compared to that observed under rocking alone. The large difference in sag factor observed with Chemical B slurries correlates with the difference in rheology between the two slurries. This last result confirms the importance of designing the slurry with the right viscosity for minimizing settling potential.

These test results seems to suggest that there is little synergistic effect between vibration and rocking motions on the slurry stability and that rocking is the main cause of solids settlement.

The 1% v/v chemical treatment was sufficient to stabilize slurries under both rocking and vibration.

Discussion

Drilling waste slurries are heteregenous in nature and characteristics and properties of the slurries will be dependant of the drill cuttings type. The particle- size distribution is a critical parameter, as it will control the slurry viscosity. In our study, grinding of the particles has been maximized in order to simulate the worst-case scenario. The results reported show that engineering the slurry, in terms of the chemical treatment, can significantly improve both slurry stability and pumpability.

Addition of 1% v/v chemical treatment was effective in improving slurry stability and high solids concentration can also be achieved (up to 40% v/v).

The boat rocking is the main contributor to particle settling but addition of 1% v/v chemical treatment stabilizes slurries.

Conclusions

- Cuttings characteristics are very variable and slurry properties will vary a lot from one cuttings type to the other. With such variability, pre-testing of the cuttings will have to be conducted in order to adjust the chemical treatment.
- Effect of rocking and vibration motions was studied in the laboratory. Rocking motion is the main factor inducing slurry settling. There is a little synergistic effect between rocking and vibration.
- A correlation between viscosity and settling potential exists. The higher the yield point, the lower the sag factor. A minimum YP of 60 lb/100 ft^2 is required to get good slurry stability.
- Effect of chemical treatment on slurry stability was studied. Chemical treatment can stabilize the slurry under rocking and vibration and decreases slurry settling potential.

Acknowledgements

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Table 1 : Cuttings Characterization

SG	1.8
CEC (meq/100g)	22.0
Oil Content (% w/w)	8.0
Reactive Clay (%)	28.0
Quartz (%)	44.0

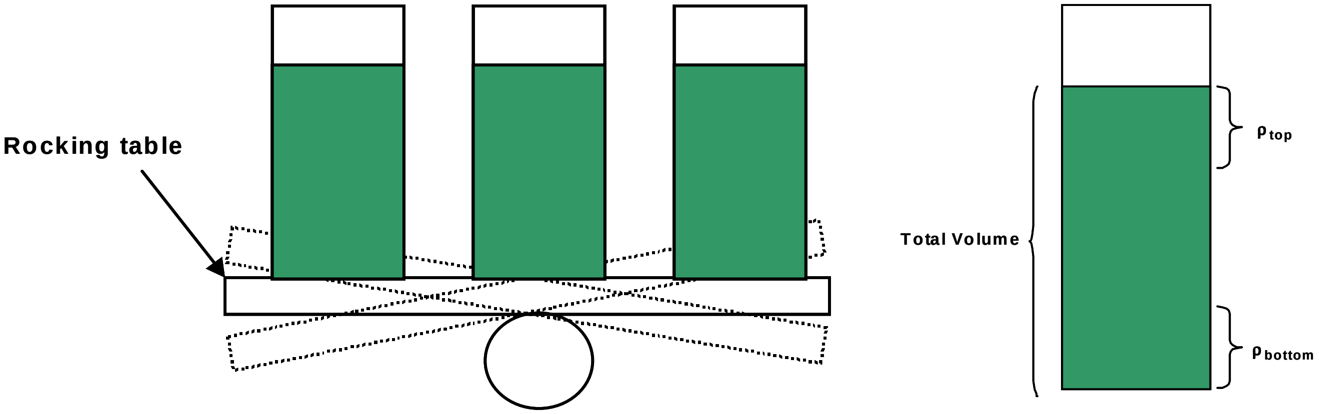


Fig. 1 - Rocking Table Set-up.

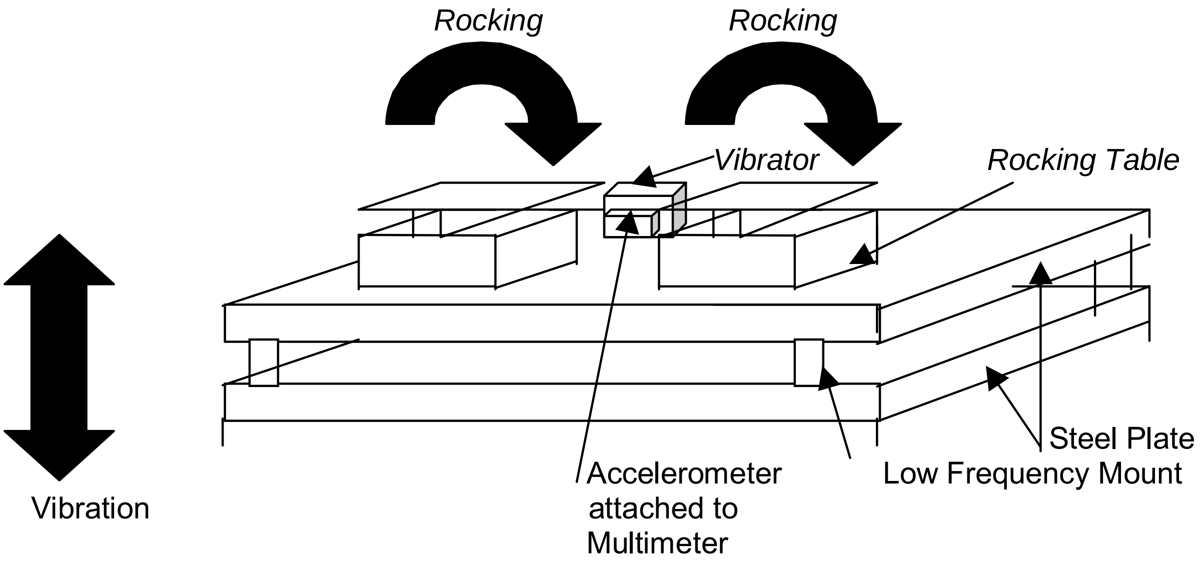


Fig. 2 - Vibrating Table Set-up.

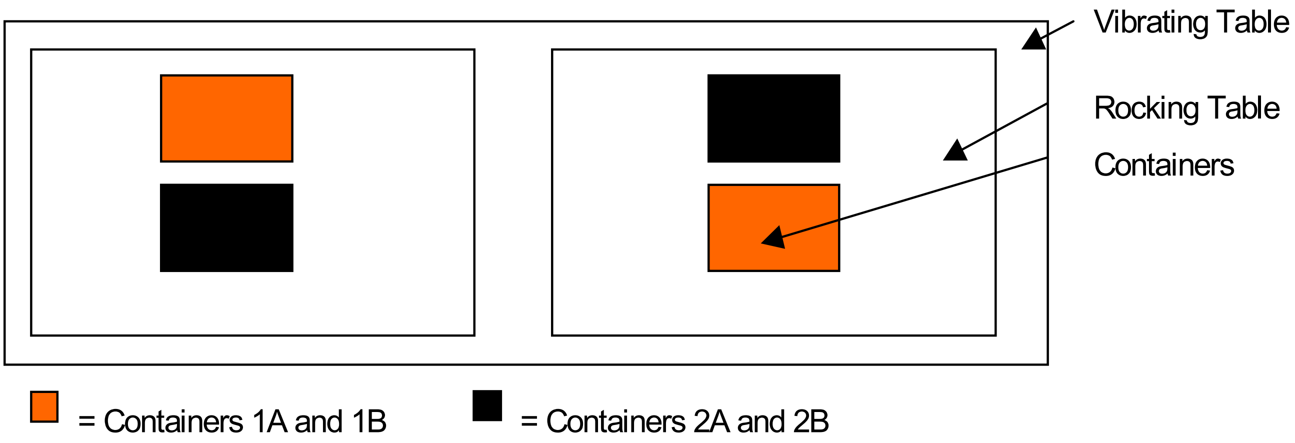


Fig. 3 - Positions of the container on the Vibrating Table.

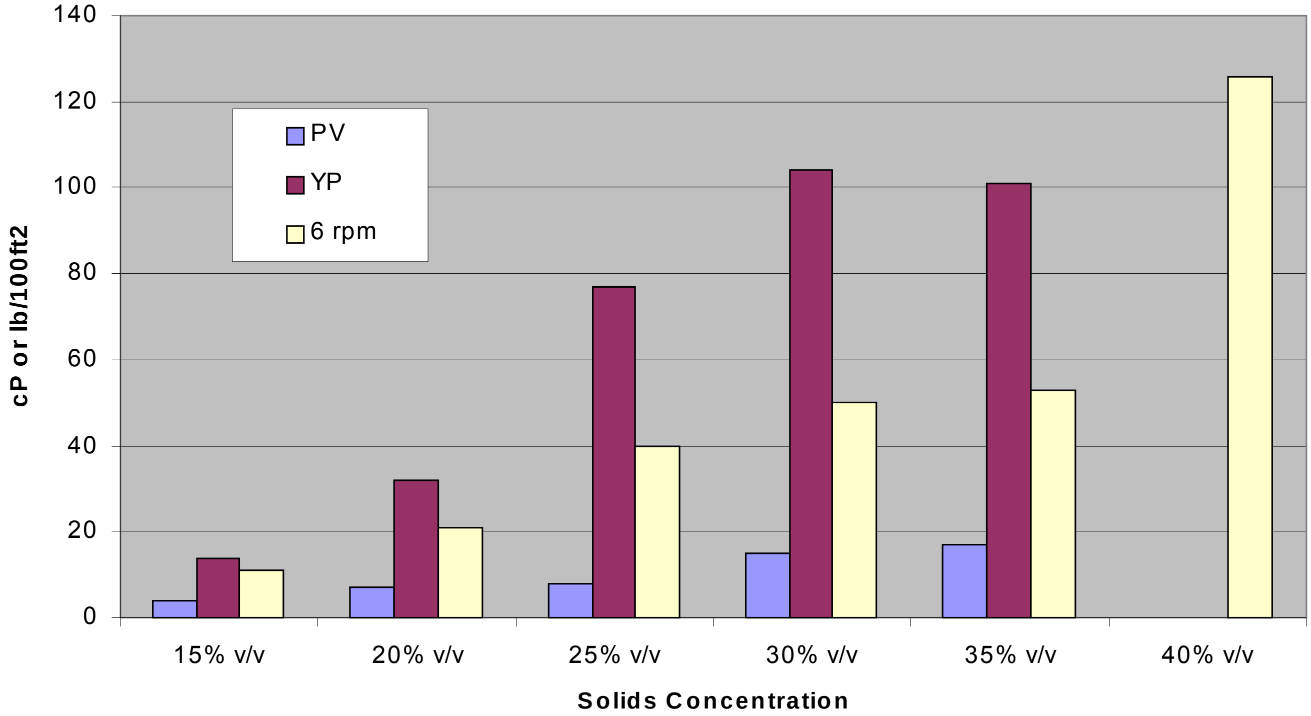
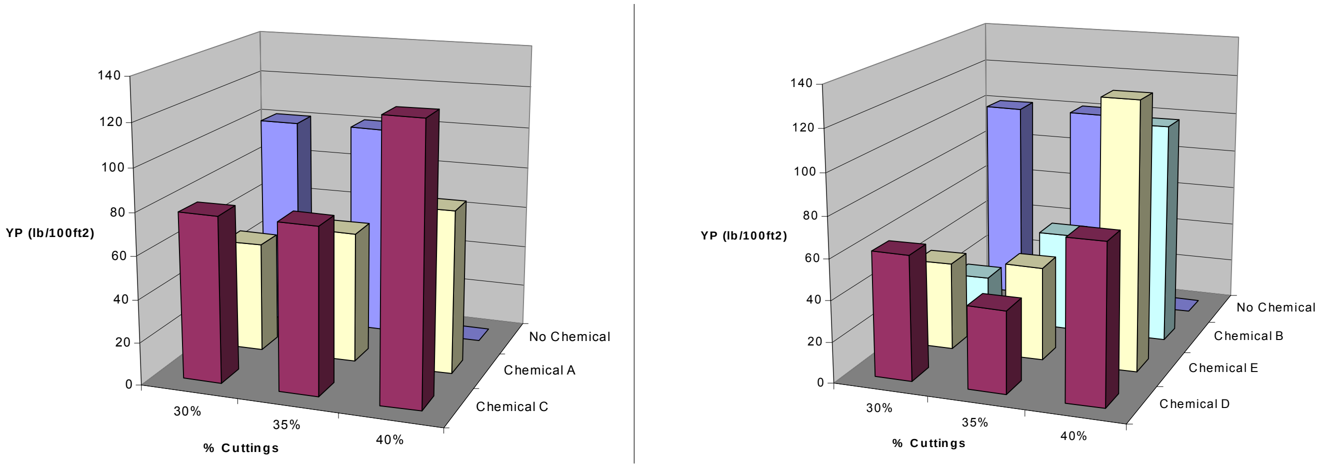


Fig. 4 - Effect of solids loading on slurry viscosity.



NB : 40% cuttings – No chemical treatment : Slurry were too thick for viscosity measurement

Fig. 5 - Effect of chemical treatment and solids loading on slurry viscosity.

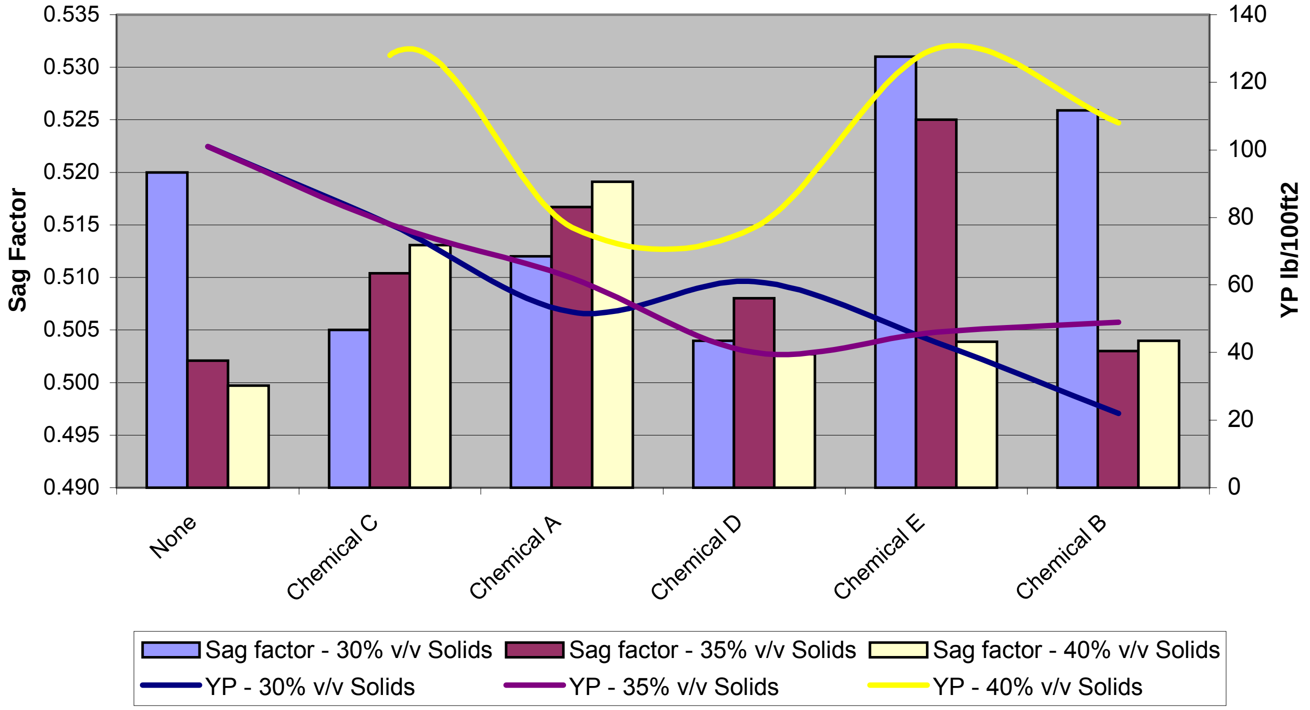


Fig. 6 - Effect of Rocking on settling.

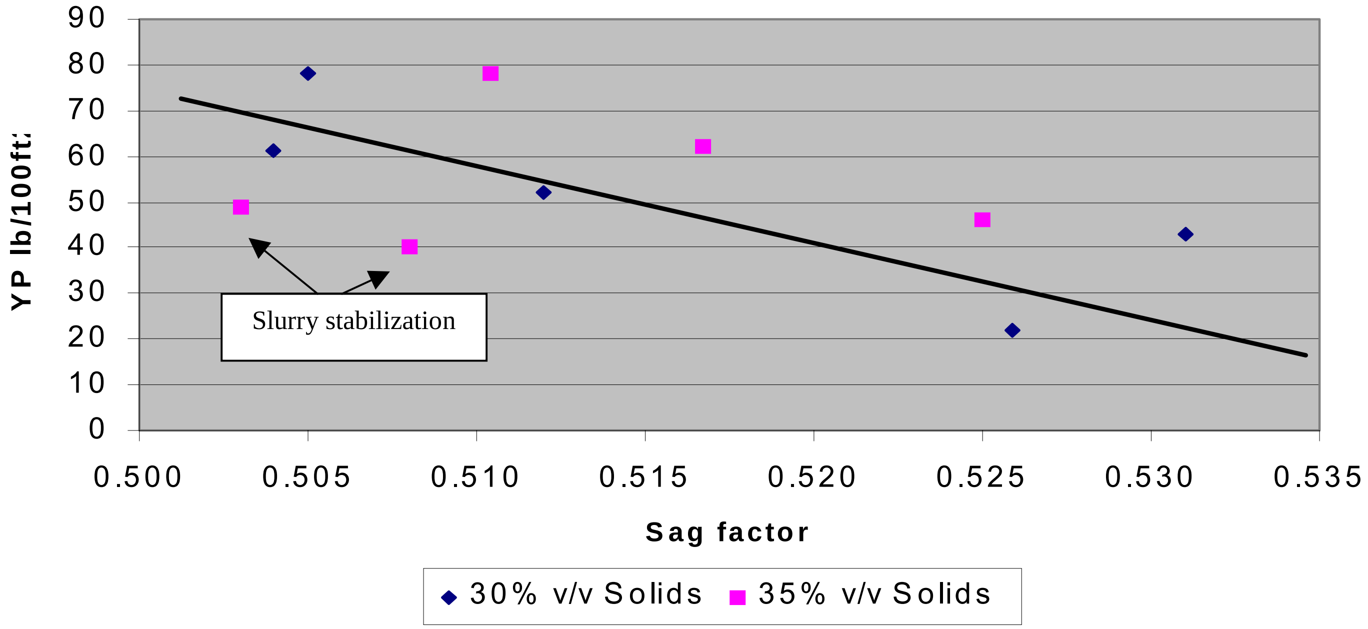


Fig. 7 - Correlation between Sag Factor and YP under rocking.

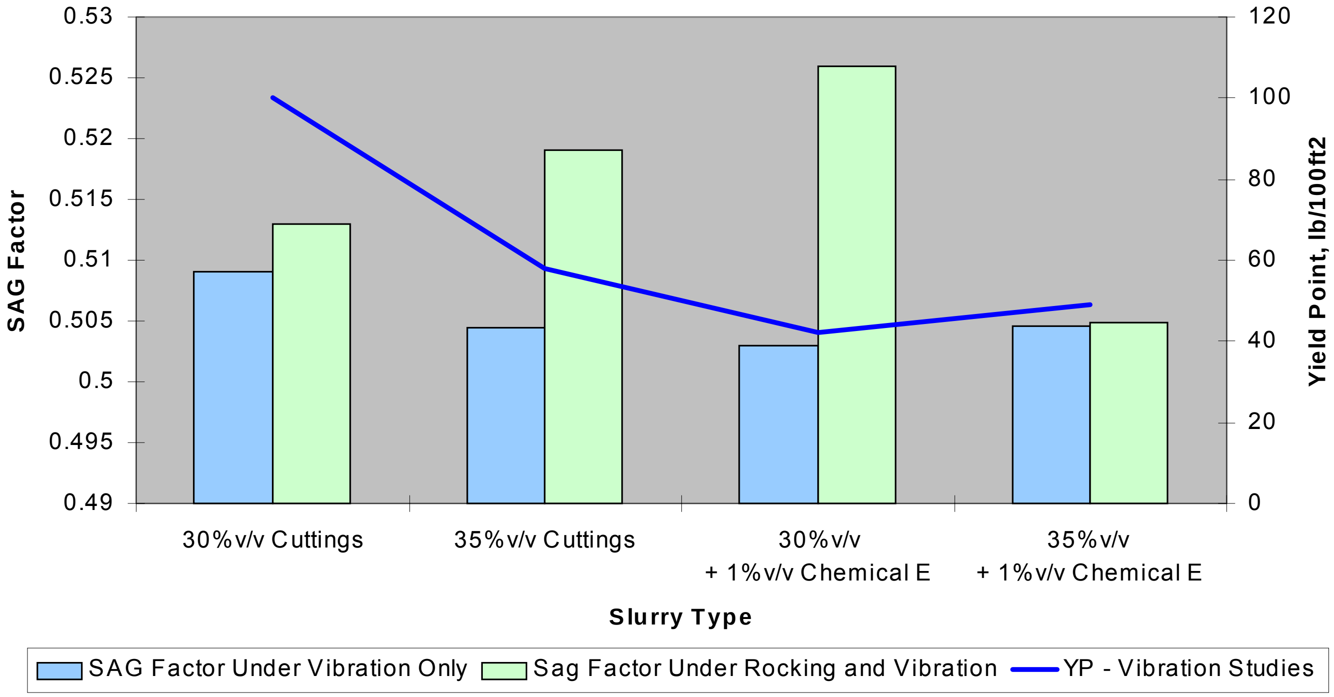


Fig. 8 - Significance of vibration effect on sag factor.

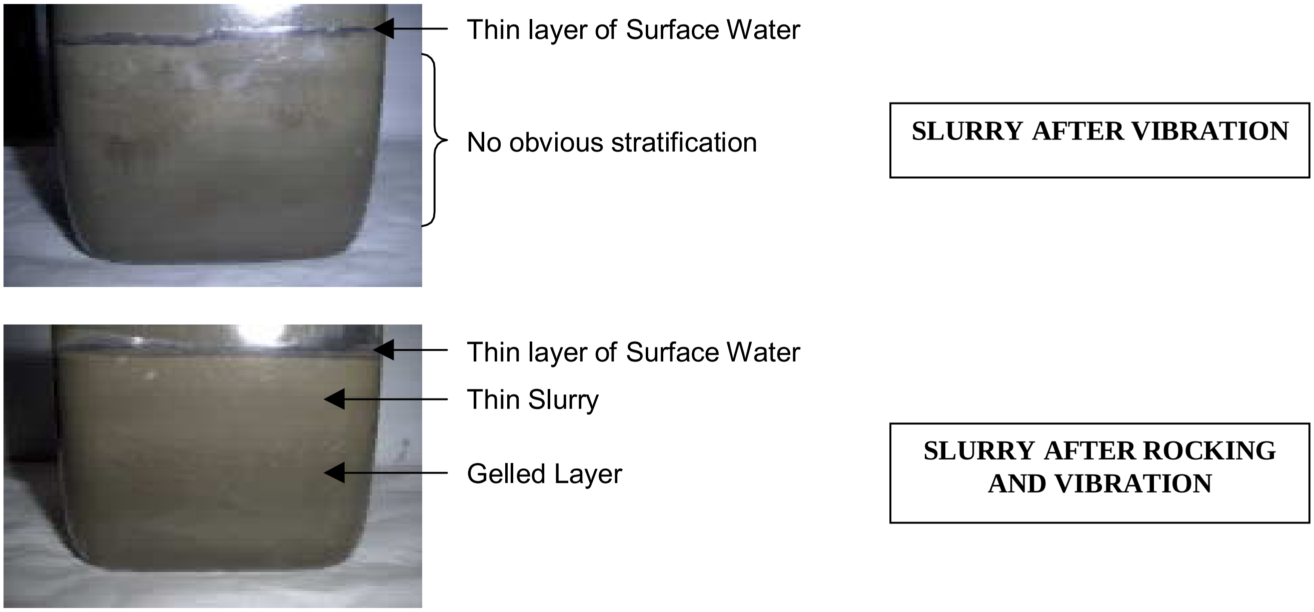


Fig. 9 - Effect of vibration and rocking on slurry stability.

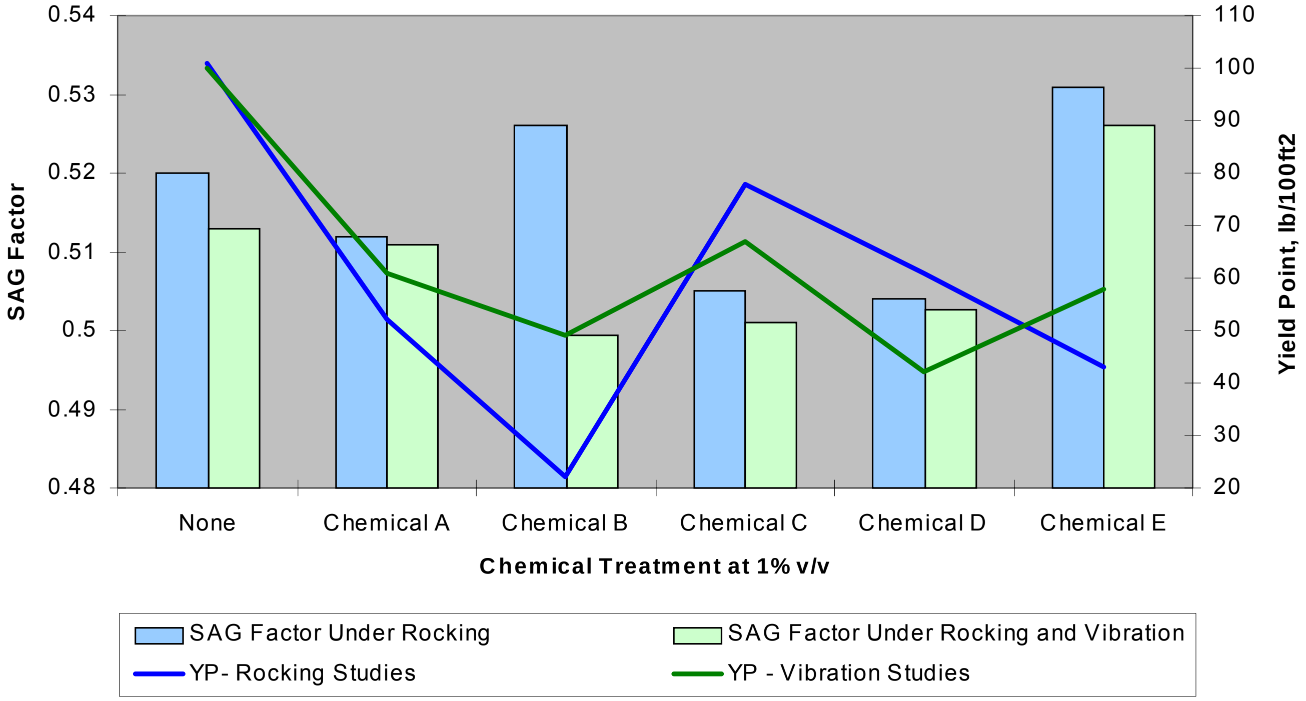


Fig. 10 - Effect of Rocking and Rocking and Vibration on slurries stability using 30% v/v Solids slurries.