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## Study of Cuttings Transport Using Stable Foam Based Mud in Inclined Wellbore

S.R. Suradi, N.S. Mamat, M.Z. Jaafar, W.R.W. Sulaiman and A.R. Ismail

Petroleum Engineering Programme, Faculty of Petroleum and Renewable Energy Engineering, Universiti Teknologi Malaysia, UTM, Johor Bahru, 81310, Johor, Malaysia

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#### Corresponding Author:

S.R. Suradi,  
Petroleum Engineering Programme,  
Faculty of Petroleum and Renewable  
Energy Engineering,  
Universiti Teknologi Malaysia,  
UTM, Johor, Bahru, 81310, Johor,  
Malaysia  
Tel: +60176021552

### ABSTRACT

Drilling of high angle, horizontal and other more complex trajectory wells are common strategies to economically produce hydrocarbon from the reservoirs. During directional drilling, hole cleaning is a vital aspect which needs to be monitored and controlled. For this purpose, foam-based mud using the Under Balanced Drilling technique (UBD) is employed to obtain a better cutting transport. Solid particle is one of the lubricating agents that is widely used in water-based mud. Previous studies have shown that microbeads could significantly reduce the friction in water-based mud. However, the application of polymer beads in foam-based mud is yet to be proven. Similar to the improvement in the water-based mud, it is expected that polymer beads such as Styrene Methacrylate could enhance the rheological properties of the foam-based mud. The polymer beads might significantly reduced the torque and drag by reducing the coefficient of friction of the foam-based mud. Polymeric particles could act as the foam or emulsion stabilizer which improved the stability of the foam. The half-life of the bubbles could be extended due to the addition of polymers. The fine sizes of the polymer beads were enhanced the stability of bubbles. Theoretically, the gas phase in the foam drilling mud was pulled the cuttings upward because of their buoyancy, thereby counteracting the gravity force. Therefore, the more stable the bubble in the foam drilling, the better the cuttings transportation will be. Introduction of polymer beads in the foam-based mud improved the foam stability. Reduction of the torque and drag force improved the carrying capacity of the cuttings in directional drilling. The suitable lubricating agent can reduce the drilling operation problems such as stuck-pipe. This will result in smooth drilling operation and great benefits in term of economy.

**Key words:** Stable foam based mud, cutting transport, styrene methacrylate, under balanced drilling, deviated angle hole

### INTRODUCTION

Nowadays, the drilling trend is focus on drilling of high angle, horizontal and other more complex trajectory wells due to the economical benefit. Optimal hole cleaning refers to the efficient removal of drill cuttings during drilling. To efficiently transport cuttings out of the hole, the transporting medium (drilling fluid) must be able to suspend the solid particles, also, there must be enough energy in the form of motion to push the solids out of the hole. Cutting suspension and transport is one of the most important properties to be considered when

selecting the drilling fluid. As the hole inclination start deviated from vertical to horizontal, additional challenges rise, such as cuttings bed development. Cutting tend to settle down and start to form cuttings bed which can become stationary thus making progress in drilling difficult and requiring frequent and expensive cleaning activities.

During directional drilling, cutting removal become more difficult and required proper control because it could cause serious problems such as mechanical pipe sticking (fishing or loss of hole), excessive frictional torque (increase in rotary power requirement) and frictional drag (inability to reach

the target), difficulty in casing landing, channeling problems during cementing and difficulty in logging (Nazari *et al.*, 2010).

Among the different techniques to achieved under balanced condition, foam has been proved to be strong candidate as a drilling fluid in under balanced drilling because of its variable density and its high effective viscosity. The high viscosity of foam makes it an efficient medium for cutting transport at any size of cutting generated can be brought to surface with foam. The behavior of low-density fluids in under balanced drilling foam is very beneficial due to its encouraging cutting carrying capacity. Foam is the most versatile aerated fluid which is designed by mixture of gas phase and foaming solution. It is one of the most capable fluids for cutting lifting and wellbore cleaning (Peysson and Herzhaft, 2005).

Basically, previous studies about foam based mud are more focus on the foam rheology. The knowledge of foam properties, especially the flowing properties is still incomplete. The current trend in the foam research applied the solid to stabilize the foam. The approach in this study is applying the polymer beads as the lubricity agent and stabilize the foam and the effectiveness in transport various size of cutting is observe with the effect of flow rate and pipe rotation.

During the deviated and high angle well, the drill string always tend to lie on the low side of the drilled well due to gravity. Walker and Li (2000) concluded that solids are more difficult to be transported when the pipe is located near the bottom side of the hole. When this happens, the velocities in the narrow gaps close to the pipe are very low and this will cause solids to be deposited rapidly. This effect tends to be accentuated if the viscosity increases, as the drag forces on the liquid will reduce the velocity in the narrow gap the more. As the inclination of the well increases towards the horizontal, the amount of fluid needed for proper hole cleaning increases. In conclusion, hole cleaning time is affected by the position of the pipe within the well bore. In order to optimize hole cleaning, reliable method to predict pipe eccentricity is needed.

It has been suggested that cutting transport is made easier in the presence of drill pipe rotation. Semi-consolidated beds can in some cases be removed because the drill string drags a large portion of the bed around from the bottom of the annulus to the top where a high flow rate is the high flow rate can then disperse the removed cuttings to some degree and good hole cleaning may be achieved. This behavior is particularly a possibility for removing sand beds and other non-reactive cutting particles (Saasen and Loklingholm, 2002). Pipe rotation tend to make flow turbulent and this turbulent like motion makes the frictional pressure loss to increase, causing an increased shear stress on the cutting bed surface. This increased shear stress will assist in cutting removal.

One of the Under balanced drilling techniques which is foam based drilling fluid has a good lubricating characteristic and hole cleaning capacity. Foam should be stable in the presence of oil or salt if brine is required as the liquid phase. Besides, foam is a thermodynamically unstable fluids and its rheology is more complex, therefore, it is important to select the suitable foaming agent in order to maintain stability of the

foam. Foam structure is best preserved using an effective surfactant which enables the formation of stable interfacial surfaces and suitable viscosifier that will reduce the rate of foam break mechanism (Hutchins and Miller, 2005).

This study will considered the hole inclination around 40-60 degrees which is inclinations from horizontal to 50 degrees constantly for every experiment. As the inclination angles around 40-60 degrees, the hole cleaning is most difficult due to the back sliding of the cutting inside the wellbore. Ogunrinde and Dosunmu (2012) stated that the range of hole angle from 35-60° (from vertical) is the most difficult for cuttings transport. Frictional pressure losses in a deviated wellbore highly depend on cuttings bed thickness. In this research, pressure transducer will be applied for pressure measurement during the experiment.

Pipe eccentricity is hardly achieved in most wells, in eccentric cases the pressure loss and thereby the ability to remove cuttings is increased because the effect of pipe rotation causes fast flowing fluid from the wide part of the hole down into narrow sections sandwiched between the formation and the drill pipe. Abdulsalam (2010) classified eccentricity occurs when inner pipe is not precisely centered in the wellbore.

Ozbayoglu *et al.* (2008) concluded that the pipe rotation has a significant improvement on cuttings transport, especially if the pipe is making an orbital motion. Also, pipe rotation drastically decreased the critical fluid velocity required to remove the stationary cuttings bed totally. In the single phase flow, the frictional pressure losses increased as the pipe rotation speed increased and as the cutting were introduced, frictional pressure losses might decrease with increasing rotary speed due to the reduction in the stationary cuttings bed area.

According to the Duan *et al.* (2008), the finding from the experimental concluded that the reduction in cuttings concentration was up to 40% at the medium velocity when the pipe rotated up to 120 rpm. The reduction in frictional pressure loss was up to 50% at the medium velocity and up to 60% at a low velocity. The cuttings concentration decreased with pressure and increased with temperature and the frictional pressure loss increased with pressure and decreased with temperature.

The objectives of this research are to evaluate the effectiveness of polymer beads (styrene methacrylate) in foam-based mud as stabilizer and lubricant agent by observing the half-life of the foam, rheological and lubricity testing and to assess the performance of stabilized foam as drilling fluid in cuttings lifting operation with various sizes of cutting, flow rate and pipe rotation effect.

## **MATERIALS AND METHODS**

The stability of the foam will be investigated by comparing the performance of basic foam based-mud and foam based-mud with additional Xanthan gum and polymer beads. The stability of foam will be observed by the different concentration of salt contamination. The lubricity performance and rheological properties will be compared between basic foam-based mud and foam-based mud with



Xanthan gum and polymer beads. Other than that, the cutting transport performance will be compared with the effect of pipe rotation which is not more than 120 rpm with various flow rate of foam and size of cutting. Then, the cuttings carrying capacity was tested by using the designing flow loop for dynamic testing.

The materials which used in this study comprised polymer beads, foam-based mud and mud contaminant. The study contains static test and dynamic test. In the static test involving the stability, rheology and lubricity test. While dynamic test is the carry capacity test using the designed flow loop. In these research two types of foams based mud will be prepared which is shown in Table 1.

**Stability test:** The foam stability of aqueous foam was evaluated by using the Ross-Miles method which based on the half-life measurement. The method is based on measurement of the liquid phase drained volume as a function of time in ambient condition. The various concentrations are applied for study the effect salt contamination on foam stability studies are as stated in the Table 2. The stability of foams in surfactant, polymer and the presence of salts was studied by using this method.

Foams will be prepared by stirring 100 mL of the foaming solution in a blender at 20000 rpm/22°C for 30 sec. Then salt is adding with continuous agitation for 30 sec. The foam is then immediately transferred to a 1000 mL graduated cylinder and the drained volume is registered at 1, 2, 3, 5, 7, 10, 14, 20 and 25 min. Also the time (in seconds) when the half of total liquid phase volume (50 mL) is drained was recorded. This value is called the time half-life ( $t^{1/2}$ ). Figure 1 shows the blender agitation using for foam stability test.

**Rheological measurement:** The rheology of foam based mud was measured by using the Brookfield viscometer (Fig. 2) which include the measurement of apparent viscosity, 10 sec gel strength, 10 min gel strength, plastic viscosity and yield point. Viscosity and shear stress will be measured at 27°C. This experiment will be conducted on different types of foaming solution (standard foam formulation and standard formulation added with xanthan gum and polymer beads)

Table 1: Ingredients for foam-based mud

| Chemical reagent                     | Description                       | Composition (volume) |                |
|--------------------------------------|-----------------------------------|----------------------|----------------|
|                                      |                                   | Mud 1                | Mud 2          |
| Tap water                            | Liquid base                       | 100 mL               | 100 mL         |
| Sodium dodecyl sulfate               | Surfactant                        | 1% of solution       | 1% of solution |
| Xanthan gum                          | Viscosifier                       | 0.3% of solution     | None           |
| Polymer beads (styrene methacrylate) | Particle stabilizer and lubricant | 3% of solution       | None           |

Table 2: Concentration of mud contamination

| Type of mud contamination | Concentration (wt. %) |
|---------------------------|-----------------------|
| Salt ( $\text{NaCl}_2$ )  | 5, 10, 15, 20, 25     |

by measuring the viscosity at different rpm (5-rpm) by rotating a spindle while immersed in the foam.

**Lubricity measurements:** The lubricity testing will be conducted by using the Lubricity Evaluation Monitor (LEM)-4100 which comprised a rotating bob, housed in a small pressure vessel, used for lubricity testing of oil well drilling and completion fluids at surface and downhole temperature and pressure conditions. The test will be conducted at the



Fig. 1: Blender agitation method



Fig. 2: Brookfield viscometer

normal temperature which is 60°F. This experiment was conducted on different types of foaming solution (standard foam formulation and standard formulation added with Xanthan gum and polymer beads) by measuring the coefficient of friction. The Lubricity Evaluation Monitor was used in the experiment as in Fig. 3.



Fig. 3: Lubricity Evaluation Monitor-4100

**Preparation of cutting:** Different size of cuttings were prepared by using the sand which categorized into fine, medium coarse and coarse. The exact chosen sizes of cutting are 0.25, 0.50, 1.00 and 2.00 mm. Same type of sand was sieved by using sand sieve shaker into the respective size required. Each size of cuttings was then segregated into 200 g per pack which made up total of 1 kg used. The different of cutting size was tested through the designing flow loop in order to studies the effect of sizes in the cutting transport. Standard foam based mud with additional of Xanthan gum and polymer beads were used to test sizes of cutting effect.

**Cuttings carrying capacity test:** The following Fig. 4 showed the loop of cutting carrying testing for the stable foam based mud. The angle inclination of the well will be set constantly at the 50° due to study the effect of pipe rotation and velocity of foaming agent at the worst angle of well. The flow loop consists of an annular testing section, a pump, an air compressor, a foam generator, flow meter, a cutting injection tank, a collector tank, pressure transducer and rotary motor.

The experiment had done under the room temperature and pressure. Faom generator which consists of stainless cylinder packed with glass beads of 3 mm in diameter. It is set at the entrance of the test section to provide better mixing between gas phase and liquid phase. A pressure loss will be measured at 1m long in the outlet of the test section by means a pressure

Table 3: Equipment capacity

| Equipments                      | Capacity                        |
|---------------------------------|---------------------------------|
| Pump capacity (Flowrate)        | Maximum: 60 L min <sup>-1</sup> |
| Tank volume                     | 159 L                           |
| Cuttings air injector pressure  | 4 bar                           |
| Nitrogen gas regulator pressure | 250 kpa                         |

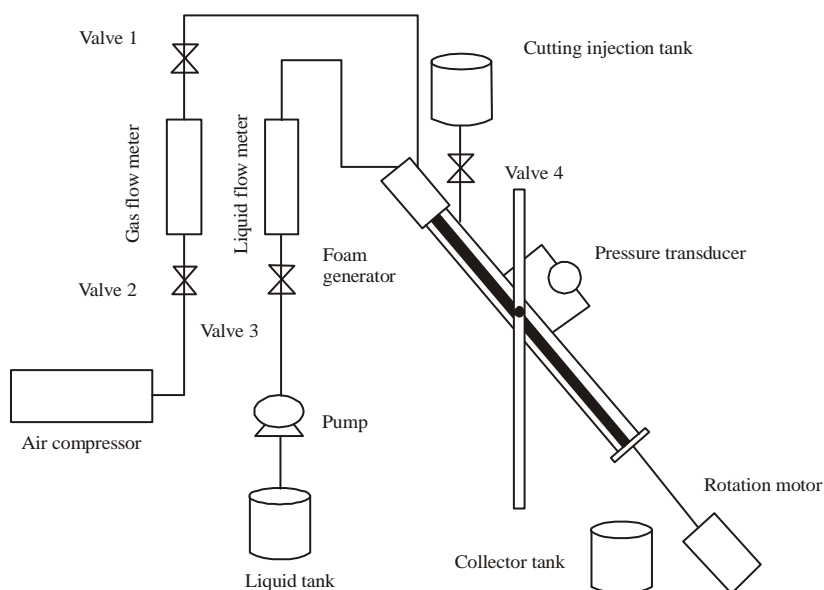


Fig. 4: Flow loop system



Table 4: Pipe dimensions

| Pipe dimension      | Length/Width |
|---------------------|--------------|
| Test pipe diameter  | 2 inches     |
| Test pipe length    | 12 feet      |
| Inner pipe diameter | 0.6 inches   |

Table 5: Experimental test matrix

| Pipe rotation (rpm)   | 0-120 | 0-120 | 0-120 |
|-----------------------|-------|-------|-------|
| Fluid velocity (ft/s) | 2-4   | 2-4   | 2-4   |
| Eccentricity          | 0     | 0.25  | 0.5   |

transducer. Table 3 shows the equipment capacity that will be used in carrying capacity study while Table 4 is the properties of the pipe dimension that used to run this test.

**Test matrix:** Extensive amount of experiments will be conducted with 4 different types of cutting size which is 0.25, 0.50, 1.00 and 2.00 mm. Table 5 shows the parameter involves in the dynamic test of cutting transport and the friction pressure drop and cutting concentration will be observed.

## RESULTS AND DISCUSSION

**Effect of salt contamination on stability of foam:** In order to evaluate the effect of salt on the foam stability, different concentration of monovalent salt will be studied. This salt will be tested on the standard foam based mud and foam based mud with 0.3% of Xanthan gum and polymer beads. Figure 5 shown that the higher salinity (higher concentration of NaCl) reduced the half-life. It indicates that the addition of salts reduced considerably the stability of foams generated with anionic surfactant. Adding the NaCl will changes the concentration and viscosity of foam based mud. Hence, the drainage rate from the lamellae of foam increased. By adding the polymer in the system, the stability of foam will be increased.

**Lubricity test:** In this measurement, the polymer beads reduced the coefficient of friction of foam-based mud as if in the water-based mud. Below is the comparison of foam based mud and foam-based mud with 0.3% Xanthan gum and polymer beads. Based on the Fig. 6, the successfully improve the lubricity of foam drilling fluid in the presence of polymer beads and Xanthan Gum. The equipment used to measure lubricity was the Lubricity Evaluation Monitor (LEM)-4100.

**Rheological properties:** The rheological properties conducted including plastic viscosity, yield point, gel strength 10 sec and 10 min. The viscosity indicates the drilled cuttings suspension and hole cleaning abilities under dynamic condition. Martins *et al.* (2001) agreed that one of the primary advantages of foam is the capacity for cuttings transport. Polymer will increase the viscosity of foam based mud. This behavior can be due to the repulsive interaction between surfactant and/or because one of the components does not have high affinity to the solvent (Rojas *et al.*, 2001). Foam must be stable during measurement time, phenomena as drainage and bubble

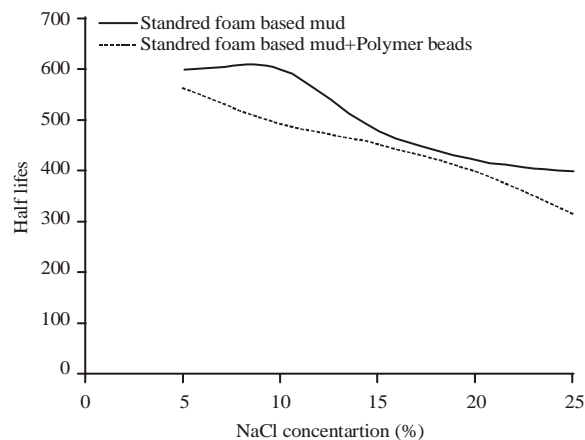


Fig. 5: Effect of salinity on foam stability

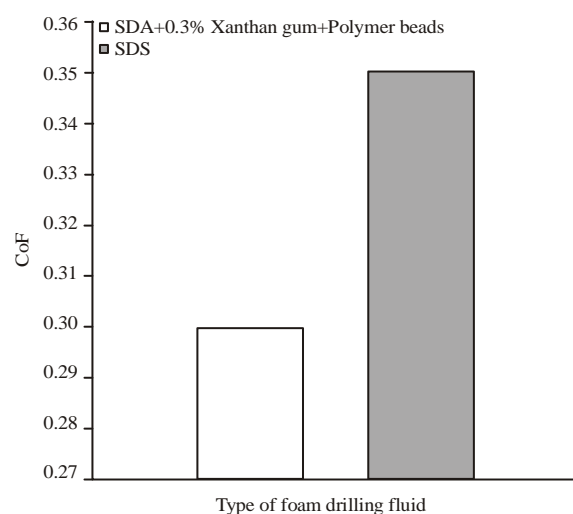


Fig. 6: Average coefficient of friction of different types of foam

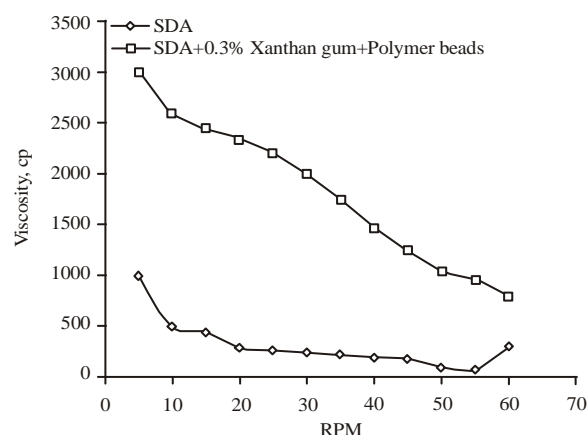


Fig. 7: Foam rheological properties of different types of foam

coalescence will alter viscosity measurement. Depending on the foam stability, the drained volume can appear more or less quickly (Fig. 7).

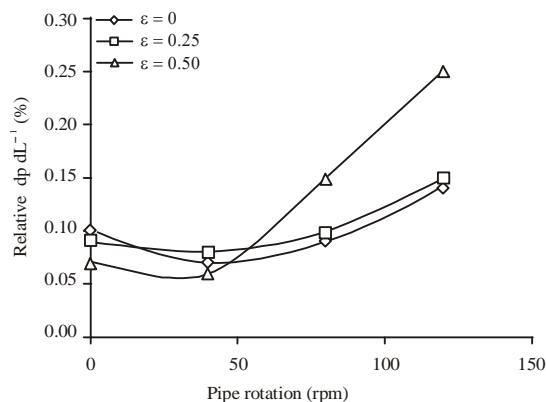


Fig. 8: Pipe rotation vs. relative pressure loss for three levels of pipe eccentricity

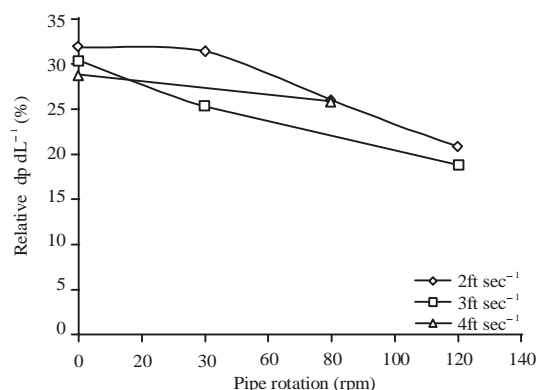


Fig. 9: Relative pressure loss vs. pipe rotation

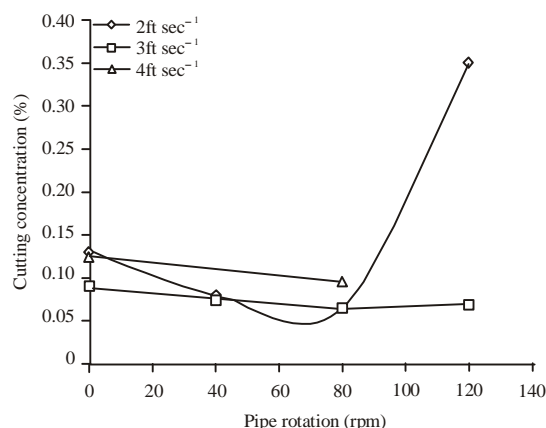


Fig. 10: Cutting concentration vs. pipe rotation

### Dynamic test

**Effect of pipe eccentricity on pressure loss:** In order to study effect of pipe eccentricity on the pressure loss, the experiment will be conducted at various foam velocities. The pressure loss will be measured and the performance of system transport the cutting will be observed. Figure 8 shows the expected finding on an increase in relative  $dP/dL$  with increasing rotation speed

across the range of pipe eccentricity. This is because the narrowing annular gap width, the effect of the rotational component of the coupled fluid velocity is greater. The increasing of foam velocity, relative  $dP/dL$  value will be decreased as the drill string begins to move and reaches a minimal value.

### Effect of pipe rotation and foam velocity on cuttings weight:

Based on the Fig. 9 and 10, cuttings concentration will be expected to consistently decrease with pipe rotation. Again, frictional pressure drop will be decreased by pipe rotation. The decrease in pressure loss with pipe rotation is mainly because of a reduction in cuttings concentration in the annulus. The reduction of cuttings concentration will be resulted in a smaller cuttings bed cross-sectional area, thus a larger open flow area for fluid. This will be reduced the flow resistance and pressure losses. The increasing foam velocity will be decreased cutting concentration.

## CONCLUSION

Applying SDS as the surfactant and additional of polymer in foaming solution will be expected the better half-life compared to other types of foaming agents.

The successfully improve the lubricity of foam drilling fluid in the presence of polymer beads and Xanthan gum. Polymer will increase the viscosity of foam based mud.

The foam with polymer beads produced better results compared to foam based mud alone as it carried more cuttings to the cuttings separator through the inclined pipe because of the rigid bubble structure that made the foam.

The increasing foam velocity will be decreased cutting concentration.

## ACKNOWLEDGMENT

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