Rheological consequences of environmental restrictions and occupational hygiene requirements while drilling offshore wells

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ABSTRACT

The article outlines several important rheological aspects of dealing with drilling and well fluids and their associated materials, chemicals and surplus materials covering the cycle from leaving the onshore key site to all surplus volumes and possible drilling wastes have met their final destination after drilling the well.

DRILLING FLUID INTRODUCTION

Drilling and completion of an oil well involves several processes. To be able to understand the rheological challenges upstream and downstream of the drilling process, it is necessary to have an overview of the drilling process without going too much into correct details.

Typically, for current North Sea oil wells, a 26” hole is drilled a few hundred meters into the formation. After this hole is drilled a steel casing is run into the hole. Cement is pumped down the inside of this casing and upwards through the annulus. Finally, all the cement is placed in this annulus and the next section, typically a 17 ½” section is drilled. After cementing a 13 3/8” casing in the 17 ½” section, a new section is being drilled and cemented. Most commonly this would be a 12 ¼” section. Finally, after drilling this section, typically a 8 ½” section is drilled through the reservoir.

One scope for the drilling fluid is to keep the well formation pressure under control at the different depths without creating too high a down hole pressure such that the formation is fractured. Another scope is to maintain a sufficient pressure to keep the hole from collapsing. The formation that is drilled will very often consist of a shale that reacts if it is brought into contact with water. Therefore, the drilling fluid contains chemicals that should hinder the dissolution of formation material into the drilling fluid, or total dispersion of clay containing material being drilled. The drilled cuttings particles have to be pumped to the surface. It is also important that the drilling fluid provides sufficient lubricity for the drill string to drill to the well target.

The study of rheological properties of drilling fluids has normally dealt with how to maintain the density of the drilling fluid by adding solid weight material, how to transport drilled cuttings and how to minimize the flow of drilling fluid filtrate into a porous formation. These traditional aspects will not be covered in this overview. The present article tries to illuminate some of the associated effects arising from transporting material from the key to the rig, handling drilling fluid and cuttings on the rig and handling cuttings for final treatment.

For simplicity, the term drilling waste is used for all materials left over from the drilling operation that needs treatment before re-use or re-cycling can occur. This term is not used as waste is used within legislation requirements and common contract language.

OIL AND WATER BASED DRILLING FLUIDS

Water based drilling fluids consist of a brine phase viscosified by polymer additives or dispersed clay systems. In addition several polymers and particles are added to prevent loss of fluid to the formation and to maintain the necessary lubricity of the fluid. The drilling fluid density is controlled by the addition of solid material like barite, ilmenite, hematite or manganese tetra oxide. Occasionally the density has been produced from the brine phase alone. When drilling shale the formation is easily dissolved into the drilling fluid. Therefore, clay inhibition polymers and glycols are often added to the fluids.

Oil based drilling fluids normally consist of a base oil, an emulsified brine phase, organophilic clay and weight material. Oil does not react with shale formations. These fluids contain enough emulsifiers and wetting surfactants to oil wet all drilled surfaces and to entrap water from the formation in the drilled solids into the emulsion.

The volumes of excess drilling waste produced when drilling with water based drilling fluids are typically in the range 4-6 m^3/m^3 drilled formation. If the formation temperature becomes high, above 150^oC, the production of the excess drilling waste increases. Drilling waste volumes in the range 6-15 m^3/m^3 drilled formation is often seen. These volumes are in strong contrast with similar volumes when drilling with oil based drilling fluids. In such cases the production of excess drilling waste is typically in the range of 1-2 m^3/drilled formation.

There is a difference in drilling operations depending on the choice between oil and water based drilling fluids. The oil based drilling fluids have normal a significant better lubricity than water based drilling fluids. Sliding friction factors in the range 0.10-0.15 are common when using oil based drilling fluids. These factors are typically in the range 0.25-0.4 when using water based drilling fluids. Therefore, deviated and long reach wells are more easily drilled with oil based drilling fluids. Hole cleaning, the ability to remove drill cuttings, is also more easy when using oil based drilling fluids. These fluids do not develop “real” gels. This lack of real gels seems to make it easier to remove cuttings from a down hole bed.

HANDLING OF BULK MATERIALS

To maintain the desired density of the drilling fluid, or well cement, it is most common to add a solid weighting agent to these fluids. The most commonly used materials in Norway are barite and ilmenite. These materials, along with bulk cement, are delivered using pneumatic conveying systems. As illustrated in Fig. 1, excess flow of bulk powder occasionally occurs when transferring from onshore-based tanks to the applications on the well site. Currently, 4-6% of bulk material is lost before the material is entering the well. Some portions are lost at the key site as shown in Fig. 1, and other portions are lost while transferring to the rig or while performing an internal transfer on the rig.

Figure 1. Accidental discharges while loading barite at Florø base.
(Photo: Are Fjellstad, Florø 1989)

WORKING WITH SOLIDS CONTROL EQUIPMENT WHILE DRILLING

After the drilling fluid has been pumped down into the well and has returned to the rig surface carrying the drilled cuttings, these drill solids have to be removed from the drilling fluid. The primary tools for removing drill solids are shale shakers. In these devices the drilling fluid flows through a vibrating screen while the drill solids is separated off.

The efficiency of shale shakers depends strongly on the rheological properties of the drilling fluid. The flow through the screens involves relatively high elongational rates. Therefore, these devices operate best if the drilling fluid is viscosified with low molecular weight polymers, or if oil based drilling fluids are used.

Most Norwegian operators will only accept non-aromatic base oils for the oil based drilling fluid. These fluids are relatively low toxic and have little environmental impact if an accidental discharge occurs. At the same time these oils are relatively low toxic for personnel working with the fluids in the shaker room.

The air quality in the shaker room is a primary focus within occupational hygiene[1,2]. There are maximum require-ments for the allowed amounts of hydrocarbon mist and vapour in the air in the shaker room. There is a relation between the base oil viscosity and the volatility of the base oils. Furthermore, the air may contain a relatively high concentration of emulsifiers in combination with water that also is temperature dependent. Therefore, it is optimum with respect to occupational hygiene to have as high viscosity of the base oil as possible.

With respect to drilling fluid performance, it is desirable to have as low viscosity of the drilling fluid base oil as possible. This is strongly in contradiction to the occupational hygiene requirements. The shale shaker performance is also optimised by the application of low viscosity base oils.

RIG SITE CUTTINGS HANDLING

Legislation and options

In most drilling operations the operations are allowed to discharge drilled cuttings if a water based drilling fluid consisted of environmentally acceptable chemicals where used. Practically, it is no longer acceptable, or allowed, to discharge cuttings drilled with oil based drilling fluids in Norway. In some rare cases discharge is still allowed if some special synthetic oil based type of drilling fluid is used. Since these types of base oils currently are phased out, they will not be discussed further in this article.

If discharge of drilled cuttings is not allowable, these cuttings particles have to be either re-injected into the formation or brought onshore for treatment. These two options will be looked at separately.

Re-injection of drilled cuttings

In North Sea practice of re-injecting drilled cuttings, the cuttings are blended with sea water to create a slurry that is pumped down the annulus typically between the 20” and 13 3/8” casings or the annulus between the 13 3/8” and 9 5/8” casings, as illustrated in Fig. 2. Occasionally the cuttings are injected into a separate re-injection well.

Normally, around $1m^3$ drilling fluid is attached to $1m^3$ drilled cuttings. The drilling fluid itself contains a large quantity of solid material. Standard practice to make a pumpable re-injection slurry is to blend one volume with cuttings, including the attached drilling fluid, with three volumes sea water. The mixture volume is processed through a slurryfication unit to a slurry with maximum 3% of solid particles larger than 300 micron. This slurry is now pumped down into the well to a location typically just underneath a large regional sand formation. The slurry creates a fracture in this underlying formation where the solid particles settles and the liquid part leak off to the sand formation. This is illustrated in Fig. 2 for a subsea re-injection operation.

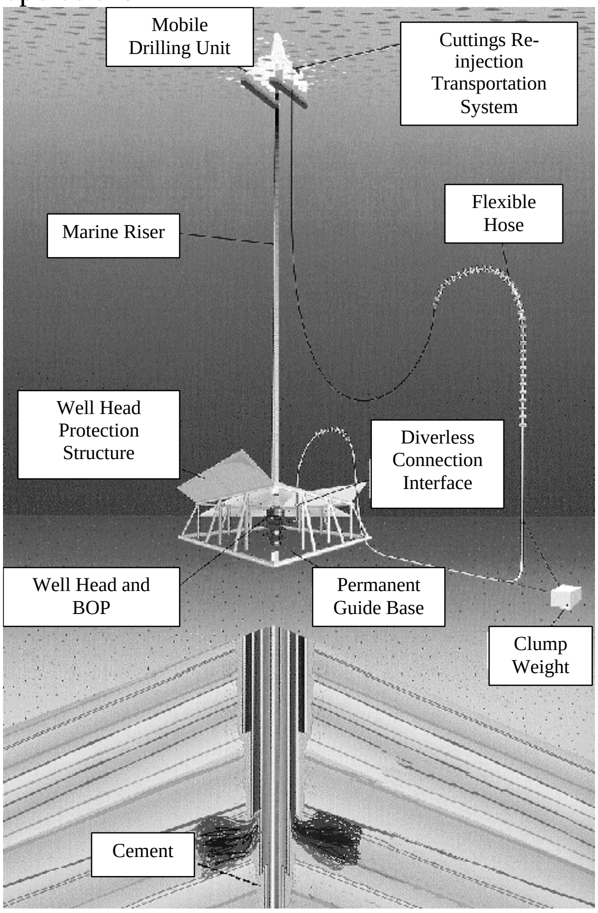

Figure 2. Principle of subsea re-injection of drilled cuttings. Consult Saasen et al.[3] for explanation of details.

The rheological challenge within this type of re-injection is to make a stable non-settling slurry that can stay in the annulus up to 24 hours. Furthermore, the rheological properties of the slurry should be sufficient to prevent excessive wear on the wellhead at the gates where the flow is entering the annulus.

The re-injection operation is one of the very few places within the offshore petroleum industry where Marsh funnel viscometers are still in use. Typical operating viscosities of the re-injection slurry would be in the range of 60-80 s/qt.

Re-injection as a method is technically straightforward both from fixed platform wells where the annulus entrance gates are on the platform or in subsea operations where an injection hose has to be mounted to a sea bottom placed wellhead using a remote operated vessel (ROV). Re-injection can be performed in the upper formation of the same well as being drilled.

In absence of large regional high permeable sand formations it is necessary to take special precautions. These precautions have a strong impact on several rheological issues. To prevent a too large fracture to build up, and to prevent the generation of a water bubble that could slowly migrate upwards in the formation, the use of seawater flushes after re-injection must be kept at a minimum[3]. Therefore, these re-injection slurries must be more stable than normal re-injection slurries. The may have to remain static in the well without any settling for 24 hours or more. Another important effect is that the fracture will expose the annulus to a large pressure over a very long time since there is no sand formation for the pressure to leak off. Therefore, the result of the cementing job in the annulus outside the annulus where the re-injection occurs must be even better than normal. The consequences are that the fluid design when running this casing has to be altered. A cement with more ductile properties must be used. Both of these two effects will require different rheological properties of the material that will be pumped. For example, it has been suggested that a foam cement could be used in this case. Currently it has been observed leakage to surface on five re-injection operations at the Norwegian field Åsgard[3]. The major causes for the leakages have been found to be improper drilling practice for the top-hole sections and improper cementing results. These operation results are strongly connected with rheological practice.

Onshore treatment of drilled cuttings

If oil wet cuttings cannot be re-injected or discharged to sea they have to be brought onshore for treatment. Common treatment options include thermal desorption of the oil, land farming, composting or application of the cuttings in industrial application[4].

The bottleneck for onshore treatment of offshore produced drilling waste is not necessarily the treatment itself. The easiest method is to transport cuttings from the shale shaker using a screw conveyor or a vacuum conveyor to skips that are lifted from the drilling rig to supply vessels for transport onshore. Access for supply vessels can be restricted by weather conditions. Furthermore, crane operations involve a severe risk for personnel working on the rigs. Therefore, it is desirable to pump or blow the cuttings from the rigs to the supply vessels.

Currently there are no reasonably inexpensive ways of pumping or blowing cuttings paste because of the very high viscosity of this material. If this problem is solved in the very near future, an increase in land-based treatment is expected.

Some chemicals used in drilling fluids can be exchanged with chemicals giving similar performance in the well, but which open for re-use and re-cycling afterwards. The weight material barite has to be changed with ilmenite or hematite if cuttings can be used in a burning process for any industrial applications. Likewise, it is not desirable to have chlorides in the water phase in oil based drilling fluids if the cuttings should be used for soil enrichment applications. These changes give a change in the rheological properties of the drilling fluid, and must be evaluated in drilling fluid engineering.

CONCLUSION

This article has outlined some consequences for rheological engineering with respect to maintaining efficient drilling operations still satisfying environmental and occupational hygiene requirements. Rheological aspects have to be re-evaluated both in bulk handling, drilling fluid application and drilling waste treatment.

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