Oilwell Drilling – The Need for Rheology Control of Drilling Fluids

Pat Kenny[1], Arild Saasen[2] and Arne Torsvoll[1].

1- Statoil, P.O.Box 300, N-4001 Stavanger, Norway
2- RF-Rogaland Research, P.O.Box 2503, Ullandhaug, N-4004 Stavanger, Norway

ABSTRACT

Drilling fluids are an integral part of the oil well drilling process and are often faced with apparently conflicting objectives. Engineers and researchers are co-operating to gain a fuller understanding of these complex fluids, especially in the field of rheology in which they are attempting to catch up on other industries.

INTRODUCTION

The purpose of this discussion is to give an insight into the role played by rheology in drilling fluids performance. Today, wells as deep as 6,000 metres and horizontal/high angle wells with horizontal displacements of as much as 7,000 metres are being drilled. Drilling fluids are a vital part of a successful drilling program and can contribute greatly to the costs of the drilling operation. Recent years have seen a greater understanding of rheology within the drilling fluids industry but it still has a long way to go if it is to reach the same level as in other industries.

HISTORICAL BACKGROUND

The history of drilling fluids can be divided into three periods[1]. The first era was one of experiment, the second one of practice and the third one of science. The first era can be thought of as beginning in ancient times up to 1901 when the famous Spindletop well was drilled in Texas which blew-out at 100,000 barrels per day. During this period drilling fluids evolved from water thrown into a well to soften the formations, and later removed along with cuttings by a bucket lowered into the well, to water being pumped through a hollow drill string to remove cuttings, and later to water to which clay was added to seal off quick sands. From 1901 to 1928 drilling fluids densifying agents such as iron cuttings, barite etc. began to be used as well as bentonite as a suspension additive. From 1928 onwards there has been steady development of drilling fluid additives.

Viscosity of drilling fluids was initially measured by a Marsh Funnel Viscometer with the viscosity being specified as seconds per U.S.quart. This was augmented first by a four speed hand cranked rotational rheometer, then by six speed electric rotational viscometers, and most recently by variable speed rotational rheometers. The industry is now using instruments such as the Brookfield rheometer to study low shear rate viscosities.

At the same time as the measurement instruments have changed so have the rheological models in use to explain fluid behaviour. The Bingham plastic was, and to some extent still is, the industry standard. This model seemed to function well enough with bentonite based fluids. With the introduction of Xanthan gum based viscosifiers the power-law model was introduced to the drilling fluids industry as the Bingham plastic model did not adequately describe these fluids. Today in the industry many people are not satisfied with either of these models and "new" models such as the modified power-law, Herschel-Buckley and Robertson-Stiff models are being introduced[2].

The drilling industry is an empirically based and very conservative industry and the acceptance of a new model will take some time - a large percentage of the involved personnel still use the Bingham plastic model. Viscoelasticity in drilling fluids has been investigated only more recently in order to gain an understanding of gel structure formation in drilling fluids.

DRILLING FLUID OBJECTIVES

Drilling fluids have a multiplicity of functions to perform and as is usual in such circumstances the final fluid design is usually a compromise. Some of the most vital functions are:

- Create a hyrostatic pressure that will prevent influxes of formation fluids and at the same time not fracture weak formations.
- Minimise formation damage which can reduce and in the worst case prevent eventual production.
- Maintain a stable wellbore in highly reactive and mechanically unstable formations.
- Function as a lubricant between drilling components and other tools and the wellbore.
- Optimise drilling bit performance.
- Remove drill cuttings from the wellbore.
- Deposit a filter cake against permeable formations to stabilise these formations and/or prevent excessive invasion by drilling mud or its filtrate.
- Satisfy environmental legislation when they are discharged either in association with drill cuttings or as whole mud.

DRILLING FLUID SYSTEMS

Trying to meet the great variety of functional requirements has led to a great diversity of drilling fluid systems. The simplest are water based with bentonite as the viscosifying agent. The bentonite can be supplemented with polymers such as carboxy methyl cellulose to adjust some of the mud properties. The next stage is to replace the bentonite with polymers such as xanthan gum and polyanionic cellulose and then add partially hydrolised polyacrylamide to inhibit the drill cuttings and add a salt such as potassium chloride to stabilise the wellbore.

Water eventually destabilises the formations encountered in offshore operations leading to the large scale adoption of invert emulsion drilling fluids with mineral oil as the continuous phase. These fluids proved extremely sucessful but environmental legislation restricted their use. This in recent years has led to the development of so called pseudo oil based mud where the mineral oil has been replaced by esters, ethers, linear chain benzenes and polyalfaolefins. Parallel to these developments water based muds have been improved by the addition of such products as polyglycols but their performance has not yet attained that of the oil based muds. As can be seen drilling fluids have developed into quite complex fluids and understanding of the different rheological properties of these fluids has constantly lagged behind their development.

WHY IS RHEOLOGY OF INTEREST?

Rheology plays a role in many of the functions of drilling fluids. Drilling fluids must be capable of efficiently transporting drill cuttings from the bottom of the well at hole angles that can vary between horizontal and vertical and enable successful removal of the cuttings at surface. Drilling fluids must be capable of suspending the densifying agent - usually barite particles, 4.2 SG - during static conditions in addition to circulation rates as high as 7,000 litres per minute.

The drilling fluid while being circulated must not generate excessive pressure losses as these can lead to the fracturing of formations or having to reduce circulation rates due to excessive pumping pressures.

The drilling fluid must prevent large amounts of drill cuttings sliding down the wellbore when pumping is stopped.

RHEOLOGICAL PRACTICE IN DRILLING FLUID ENGINEERING

The most simple models describing the shear stress versus shear rate curves of drilling fluids are models such as modified power-law, Herschel-Buckley or Robertson-Stiff models. However, as stated earlier, in standard engineering the drilling fluid rheology is most often described using the Bingham model, whether the fluid is a Bingham fluid or not. In the last decade, the power-law model has also been used. Only more recently, the modified power-law concept has been used as an alternative. The oil drilling industry is not yet prepared to take the step of complete adoption of the modified power-law model. Thus there exists, for a non-oilfield person, a self-contradicting technological terminology. Plastic viscosity and yield point are used, calculated from measured values at shear rates of 511 and 1022 s^{-1}, together with low shear viscosity values measured at shear rates of 10 s^{-1} or less.

For annular pressure loss predictions the improvement in the development of drilling fluid rheology is less necessary. The flow itself is typically unstable, although not necessarily turbulent, as a result of drillstring motion and flow in and out of cavities. The best pressure drop models are basically all empirical.

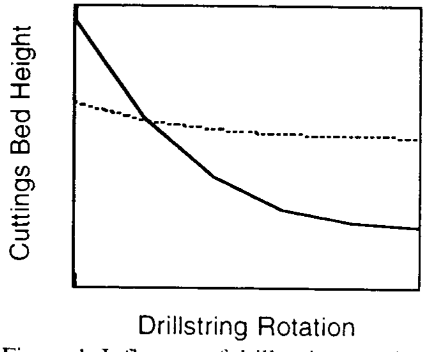

Figure 1. Influence of drill string rotation on cuttings bed height in near horizontal wells for water (----) and for a xanthan biopolymer solution (——).

There is still a significant debate on which rheological design is best applied for removal of drilled cuttings. In a horizontal well this removal seems to be optimized by using a high density Newtonian fluid in turbulent motion as long as the drillstring is not rotating. However, when the cuttings are transported up to the more vertical sections of the well, and especially when drilling fluid pumping temporarily stops, a high low shear rate viscosity and gel formation is required to keep the cuttings in suspension while the flow is stopped. Drillstring rotation enhances cuttings transport. The flow is destabilized by movement similar to the movement creating Taylor vortices. Laboratory experiments have demonstrated that removal of cuttings is better if a strongly shear thinning fluid is used than if a Newtonian fluid is used when the drillstring rotates[3] as illustrated in Fig 1. It is still questioned within the industry whether these results are sufficiently general to claim that increased low shear rate viscosity improves hole cleaning.

In deviated wells at 45-60^{o} angles from the vertical, cuttings removal is at its most difficult. A bed will typically be formed and the cuttings in the bed will move downwards while cuttings in the flow moves upwards. If there is a net cuttings flux downwards the drilling operation will be eventually halted.

Settling, so called "sag", of weighting agents, usually barite, is a serious problem in deviated drilling. To maintain pressure control and to avoid formation of a dense particle gel on the low side, it is important that the barite is always in suspension. The problem is still not thoroughly understood. However, it seems that gel formation is required to keep barite suspended when circulation is stopped. To prevent sag while circulating or while applying a small shear rate to the fluid in the well a high low shear rate viscosity is beneficial.

CONCLUSION

The oil drilling industry is in the process of aquiring a more accurate rheology model. This will lead to a greater understanding of the theory of of drilling fluids. Application of this theory should help solve some of the problems experienced today during oil well drilling.

REFERENCES

1. NL Baroid, "Manual of Drilling Fluids Technology", Houston, Texas, 1985.

2. T. Hemphill, W. Campos and A. Pilehvari, "Yield-Power Law Model More Accurately Predicts Mud Rheology", Oil & Gas J., vol. 91, Aug. 23, pp. 45-50, 1993.

3. M. Zamora, D.T. Jefferson and J.W. Powell, "Hole-Cleaning Study of Polymer-Based Drilling Fluids", paper SPE 26329, presented at the 68th Ann. Tech. Conf. and Exhibition of the SPE, Houston, Oct. 3-6, 1993.