Sensor development and calibration method for inline detection of viscosity and solids content of non-Newtonian fluids

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Abstract

To optimize, control and automate fluid flow during the drilling process, accurate and frequent measurements of the fluid viscosity, particle size distribution (PSD), solids content and density of the muddy fluid are required. This is currently done by using manually operated, batch type sensors at the surface. However, the accuracy of these devices is not sufficient to perform the required optimization and automation of the fluid flow during the drilling process. Moreover, no on site calibration procedure exists that assures a maximum measurement uncertainty.
In 2014 an EMRP funded research project started that aims at tackling these issues. The project will lead to vital information for inline measurement of drilling fluid properties. A query on operation conditions and a query on the required physical properties for Certified Reference Materials (CRMs) have been completed among the industry stakeholders. Based on the survey, a selection of the range of operating condition has been made. From the query the requirements for the non-Newtonian CRMs have been selected and documented. Three potential candidates for a CRM have been produced and distributed among NMIs for intercomparison measurements of viscosity.
The impact of non-Newtonian physics on rheology measurement techniques has been reviewed. The relevant available rheometry principles for studying gelation and gel breaking phenomena are identified. In addition, research on time dependent effects of gelation and gel breaking on rheology has been started. Influence of solids content and particle size distribution on viscosity has begun with CFD simulations.
A list of existing instruments applicable for the inline measurement of viscosity, density and solids has been produced. It has been studied which of those sensors can be applied for in-line, at-line or off-line measurements. Other relevant techniques (e.g. ultrasonic, MRI) have been added and assessed for their applicability for inline rheology measurements under operational conditions. Ten commercial rheometers suitable for in-line or at-line measurements are identified.

Introduction

When drilling deep for gas and oil or for the purpose of building bridge piles or taking core samples for a future tunnel, non-Newtonian drilling fluids are used. Such fluids are used for a variety of reasons. The pressurised fluid transports hydraulic power to the down hole drilling assembly and the drill bit, it balances the fluid pressure in the pores of the surrounding formation, stabilises the borehole walls, washes the cuttings out of the well and lubricates the drill bit [1]. Only special non-Newtonian drilling fluids have this functionality.

While drilling, fluid is pumped through the drill string to the drill bit. Typically a drill string has an inner diameter of 15 cm and a length of 1 to 10 km. The fluid flows through high-pressure nozzles mounted in the bit body against the bottom and flows back to the surface along the inside of the borehole wall taking the drilled cuttings with it, see Fig. 1.

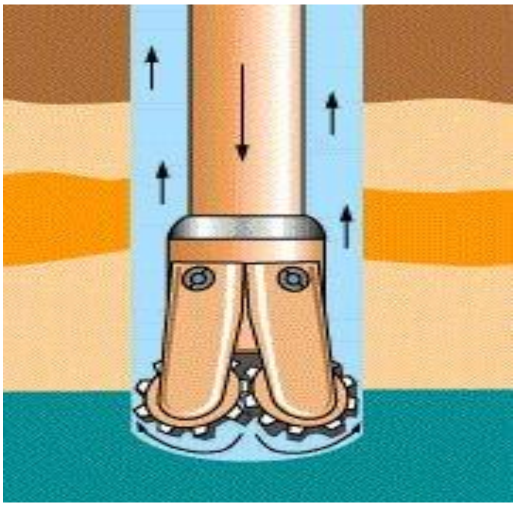

Fig. 1 Flow through a drill pipe and the borehole

The carrying capacity of the fluid depends on a minimum circulation velocity while the pump pressure required to circulate the fluid should be realistic. Moreover, at the moment that a drill pipe has to be added to the drill string, the pumps have to be switched off. In that situation, despite the fact that additional pressure required for circulation is absent, the fluid should keep the drilled solids in suspension, should still stabilise the borehole and balance the fluid pressure in the pores of the borehole formation. A problem with drilling muds is the high gel strength, quantified by τ_0 in the Herschel-Bulkley equation, see Fig. 2. Gel strength is an important property of drilling fluids as it prevents the solids from sagging when the pumps are temporarily switched off. Gel strength has to be measured at very low shear rates which is challenging for commercial sensors and the presence of solids makes this even harder.

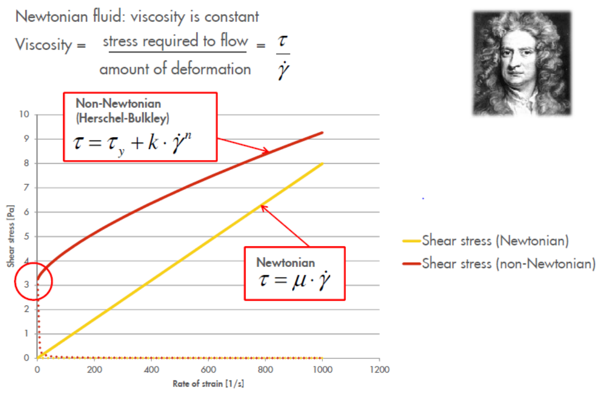

Fig. 2 Newtonian versus non-Newtonian fluids

To optimize, control and automate fluid flow during the drilling process, accurate and frequent measurement of the fluid viscosity, particle size distribution (PSD), solids content and density of the muddy fluid is required. This is currently done using manually operated, batch type sensors at the surface. However, the accuracy and frequency of the measurements of these devices is not sufficient to perform the required optimization and automation of the fluid flow during the drilling process. Moreover, no on site calibration procedure exists that assures a minimum measurement uncertainty. The automation of fluid flow is especially important for hole cleaning in extended reach drilling operations.

In 2014 a EMRP funded research project started that aims at tackling these issues [2]. The project will lead to vital information for inline measurement of drilling fluid properties, which is considered to be crucial for enabling drilling automation. In addition, improved methods for viscosity, solids content and PSD measurement will be developed. The latter will facilitate better fluid flow control during the drilling process and thereby enable improved modelling of drilling, which ultimately leads to a more secure supply of fossil fuels to Europe.

The objectives of the research project are to increase the fundamental understanding of the metrological challenges that arise when measuring the viscosity of non-Newtonian liquids. The second objective is to develop a viscosity standard for sensors for non-Newtonian liquids that is characterized by high apparent gel strength, high shear thinning properties, and a large amount of suspended solids. The third objective of the research project is to develop inline sensors that can measure viscosity, PSD, solids content and density of non-Newtonian drilling fluids.

Participants and workpackages

2.1 Participants

The partners in the Joint Research Project (JRP) are: VSL, the Netherlands, CNAM, France, IMBiH, Bosnia and Herzegovina, INRIM, Italy, IPQ, Portugal, METAS, Switzerland and PTB, Germany. There is one unfunded JRP-partner which is Shell, the Netherlands and two REGs which are IRIS, Norway and Cenimat, Portugal.
Further there is a number of collaborating institutes: Centro de Ciències Moleculares e Materials, Portugal, Anton Paar GmbH, Austria, British PetrolExp Op Co Ltd, United Kingdom, Brookfield Engineering Laboratories Inc, USA, IFP Energies nouvelles, France, The Swedish Institute for Food and Biotechnology, Sweden, Statoil ASA, Norway, Thermo Electron (Karlsruhe)GmbH, Germany, Endress+Hauser, Switzerland, Aspect Imaging, Israel [3].

2.2 Workpackages

Workpackage 1 is dedicated to the development of a set of calibration standards in the form of Certified Reference Materials (CRMs) for complex fluids in the range of viscosities, densities and temperatures that are of interest for the stakeholders. A query on operation conditions and on the required physical properties for CRMs have been completed among the industry stakeholders. Based on the survey, a selection of the range of operating condition has been made. From the query, the requirements for the non-Newtonian CRMs have been selected and documented. The main requirements are that the CRM covers the domain of drilling fluids, that the CRM is relatively easy to produce in large quantities and that the CRM is stable in time and under changing pressure and temperature conditions.

The selection of components for the potential CRM candidates has been made. Evaluation of the uncertainty of the viscosity resulting from the physical properties of existing and potentially relevant alternative viscosity measurement techniques have been assessed. Work on the development of a set of non-Newtonian calibration liquids as Certified Reference Materials with specified uncertainty budget has been started and a comparison Intercomparison protocol for CRM measurements has been created. Finally, the definition of a standardised calibration method has been completed for viscosity measurement devices measuring non-Newtonian fluids at a range of temperatures and shear rates in their operational environment.

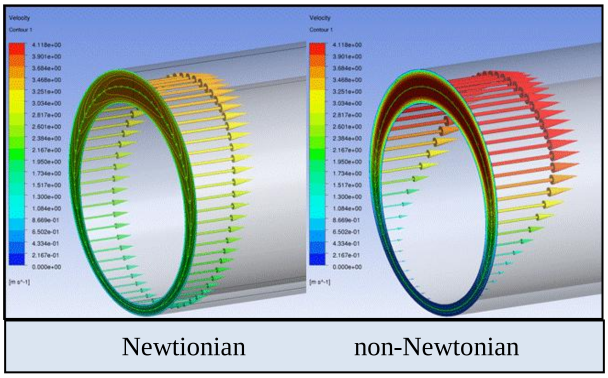

Fig. 3 Velocity profile of a Newtonian and a non-Newtonian Fluid

Three potential candidates for a CRM have been produced and distributed among NMIs for intercomparison measurements of viscosity. Measurements are ongoing and results are expected to be published in 2016. Based on those measurements the final selection of a CRM fluid will take place. The recipe for the selected CRM fluid will be published on the public section of the EURAMET website.

In workpackage 2 the impact of non-Newtonian physics on rheology measurement techniques has been reviewed. One of the main issues is the influence of shear stress on the viscosity of non-Newtonian fluids.
A list of books and journal articles has been made in order to identify the relevant available rheometry principles for studying gelation and gel breaking phenomena. Those principles can potentially be used for the study of viscoelastic behaviour of complex fluids. In addition, research on time dependent effects of gelation and gel breaking on rheology has been started. Influence of solids content and particle size distribution on viscosity has begun with CFD simulations in order to study the effect of particles present in the fluid on measurements accuracy. Extensive measurements will be performed in the second half of 2016.

Workpackage 3 focusses on sensors and calibration methods for inline measurement of viscosity, density and solids content. The current 'state of art' of rheometry in the field is measuring the viscosity of the drilling fluids with an industry standard Fann 35 device, calibrated with Newtonian liquids. A list of existing instruments applicable for the inline measurement of viscosity, density and solids has been produced. It has been pointed out that there is a possibility to phase the calibration process, namely perform coarse calibration on rig and use a fine tuning in lab conditions. It has been studied which of those sensors can be applied for in-line, at-line or off-line measurements. Other relevant techniques (e.g. ultrasonic, MRI) have been added and assessed for their applicability for inline rheology measurements under operational conditions. The primary criterion for the selection was whether the rheometer may be used to measure the fluid rheology, i.e. viscosity as a function of shear rate and across a significant shear rate range. A total of seven suitable rheometers have been chosen to be tested in the realistic operational environment at the International Research Institute (IRIS) in Stavanger, Norway.
Seven rheometers include four different rheometry based on the principles: bob and cup, MRI, ultrasonics and straight tube Coriolis. Only the conventional bob and cup method is sample based, but has been automated for at-line automatic sampling while measuring according to the API recommendation on drilling fluid rheometry measurements. Another additional feature is that some of the rheometers not only provide the viscosity parameters of the liquid, but in combination with, for instance, a differential pressure measurement, also a means to determine other quantities such like liquid density. The combination of rheometers may provide even direct information on the effect of solids content on the rheometry.
Combining different physical measurement principles reduces the systematic error in the rheometry and also enables the identification of measurement disturbances caused by, for instance, solids content or wall slip effects. Current work is focusing on recommendations for improvement of existing sensors and collaboration techniques for the inline measurement of viscosity, density and solid content.

Fig. 4 **Manually operated device for viscosity measurements**

Further interest

The energy sector is not the only industry in which it is important to monitor the non-Newtonian properties of fluids. For many manufacturers of food, paint, slurries, body care and pharmaceutical products the viscosity, density and solids content is very important for quality and process control. Similar to the drilling industry, many chemical plants require measurements to be taken in hostile working environments. To be able to do this automatically with suitable inline equipment would be a major step forward.

Conclusion

A query on operation conditions and a query on the required physical properties for Certified Reference Materials (CRMs) have been completed among the industry stakeholders. Based on the survey, a selection of the range of operating condition has been made. Evaluation of the uncertainty of the viscosity resulting from the physical properties of existing and potentially relevant alternative viscosity measurement techniques have been assessed. A set of non-Newtonian calibration liquids as Certified Reference Materials with specified uncertainty budget has been developed. A comparison Protocol for CRM measurements has been created and a standardised calibration method for viscosity measurement devices measuring non-Newtonian fluids has been defined. Measurements are ongoing and results are expected to be published in 2016.

The relevant available rheometry principles for studying gelation and gel breaking phenomena are identified. The impact of non-Newtonian physics on rheology measurement techniques has been reviewed. The influence of shear stress and the influence of solids content and particle size distribution on the viscosity of non-Newtonian fluids has begun with CFD simulations.

It has been studied which sensors can be applied for in-line, at-line or off-line measurements. Other relevant techniques (e.g. ultrasonic, MRI) have been added and assessed for their applicability for inline rheology measurements under operational conditions. A report on the applicability of all available sensors for rheology measurements in field conditions has been completed. Ten commercial rheometers suitable for in-line or at-line measurements have been identified including five very different rheometry principles: bob and cup, linear coriolis, spindle, ultrasonic and magnetic resonance imaging. The conventional bob and cup method has been automated for at-line automatic sampling while measuring according to the API recommendation on drilling fluid rheometry measurements in the field. Combining different physical measurement principles reduces the systematic error in the rheometry and also enables the identification of measurement disturbances caused by, for instance, solids content or wall slip effects. By the end of 2016 the results will be available for the public.

Acknowledgements

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References

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