Accurate ECD prediction for improved digital models

The current practice, independent on type of industry, is to create digitalized models for all industrial processes. Hence, different processes may be controlled by simple applications on computers and in many cases also on mobile phones. To be applicable, these models must be reasonably accurate. Current practice within

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drilling rely on standards like API RP13 (American Petroleum Institute, 2014). These standards base their viscosity models on measurements with VG viscometers. Earlier, all models were based on viscosity measurements at the very high shear rates of 511 and 1022 1/s to create their viscosity data. These shear rates are far too large to represent practical drilling operations. It is recommended in the current standards to use a least square fit of all shear rate measurements to increase the accuracy of the viscosity models. However, with the exception of the flow around the Bottom Hole Assembly (BHA), shear rates in excess of 200 1/s are seldom experienced in the field. Therefore, as will be shown in the following sections, an improved model accuracy will be obtained if the least square fit is conducted only for the shear rates relevant for the flow situation. These viscosity data are then used to calculate the annular frictional pressure losses in a well model experimental equipment.

Measurements and modelling

Annular pressure loss experiments have been performed in a realistic size flow loop setup with a free whirling drill string inside a cased hole (pipe in pipe). Annular flow conditions in the tests are relevant for drilling in holes from 8,5" and up to 17,5". Experiments in a similar setup representing annular flow in open hole sections are described in Werner et al. 2018. The presented data here are all from tests in a horizontal annulus (90 degrees inclined wellbore). The applied fluid is a field applied low viscosity oil based drilling fluid with density 1430 kg/m3 made with micronized barite. It is primarily used for ERD, narrow margin (low ECD) and HPHT wells.

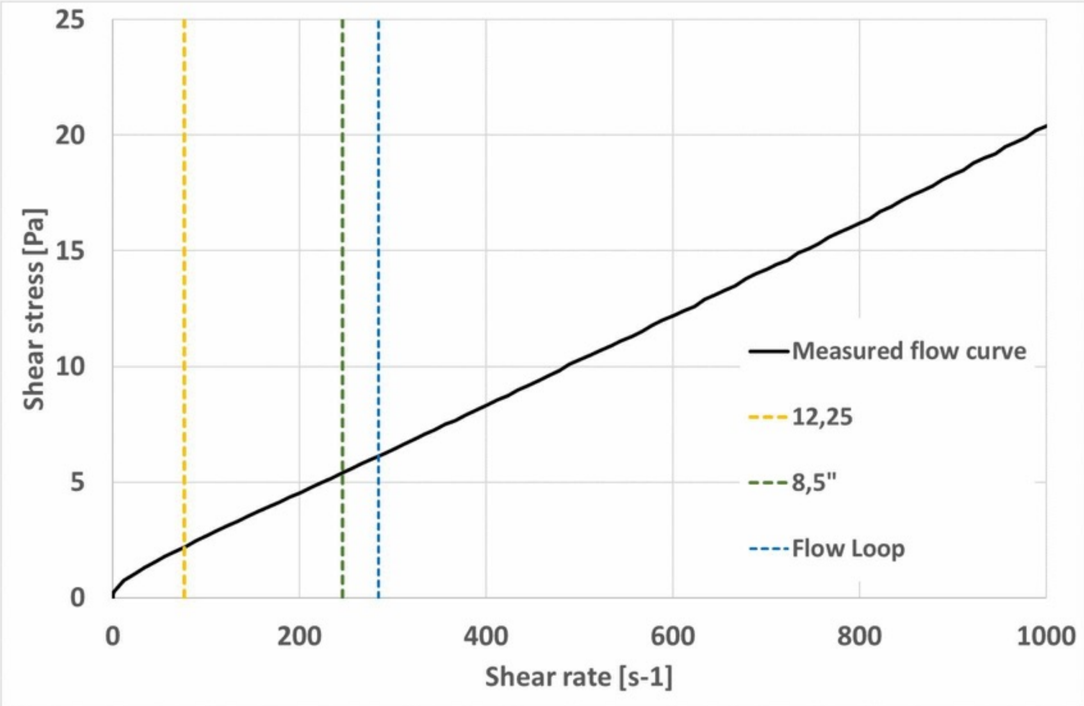


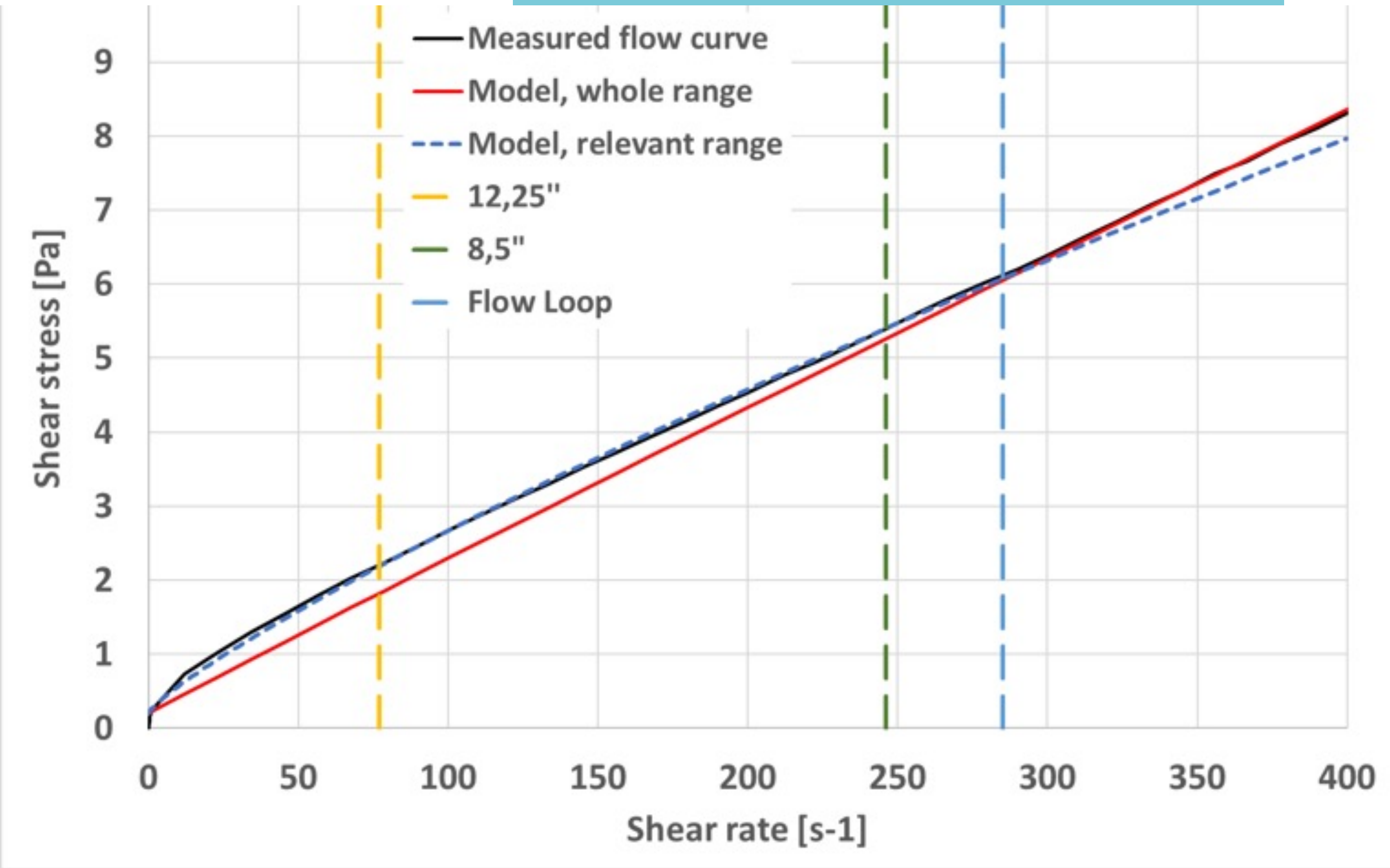
Figure 1. Flow curve is plotted for measurements according to API standards. Normal maximum shear rates for operations and flow loop are included.

References of use have been found for various North Sea fields and offshore Newfoundland, but it is applied in drilling operations all over the world. More details on the test setup and fluid details can be found consulting Ytrehus et al. (2018).

The flow curve of the oil-based drilling fluid is presented in traditional form in Figure 1. In the figure the maximum shear rates for annular flow in relevant deviated wellbore sizes are also included. These shear stresses are derived from pump capacity limits in operations. Similar maximum shear rate for the experimental setup is also included. An observation in this case is that only the lower area shear rates are relevant when considering the hydraulics and cuttings transport in the wellbore annulus. A Herschel-Bulkley viscosity model is known to present steady state drilling fluid viscosity with reasonable accuracy. The model shows the shear stress as the sum of the yield stress and the shear rate in the power of n multiplied by the constant K in the equation below:

$$\tau=\tau_y + K\gamma^n$$

Figure 2 is included, considering only the relevant shear rate range. The two Herschel-Bulkley curves are included as well: One fit by considering the whole shear rate range recommended by API and one fit by considering only



	τ_y [Pa]	K [Pa*s^n]	n [-]
Match A	0.2	0.0229	0.9806
Match B	0.2	0.0548	0.8269

Table 1. Herschel-Bulkley parameters for the two applied models are presented here.

Figure 2. Measured flow curve is plotted for the relevant shear range. Herschel-Bulkley models are applied for the fluid. One is based on measurements in the relevant shear range (0-300) and one considers the entire shear rate zone up to 1022 1/s as recommended in API standards.

the relevant shear rate range for the actual flow conditions. As seen in the figure the model considering the relevant range (Match B) has a significantly better fit in the lower shear region. Above this region the traditional fit (Match A) is significantly better. The Herschel-Bulkley parameter values of the two models are show in Table 1.

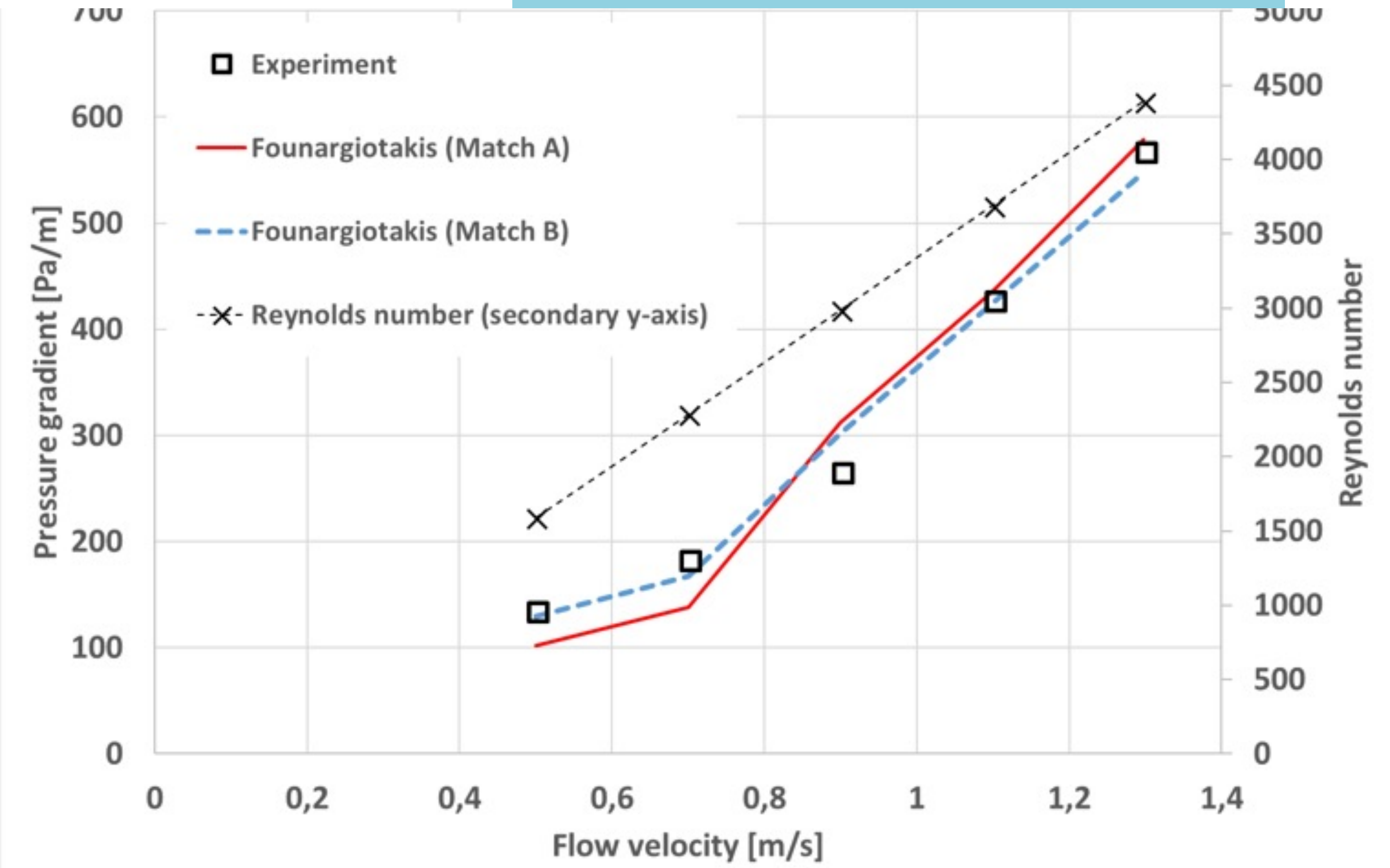


Figure 3. Pressure gradient is plotted for the experimental data and for modelling with fluid parameters based on the curve matches A and B. The corresponding Reynolds numbers are also included.

Experimental results from annular pressure drop tests are presented in Figure 3. The pressure gradient is calculated using a model described by Founargiotakis et al. 2008 for the two fluid parameter sets. The results show that the match between model and experiments is significantly better if fluid model based on relevant range is used. Some deviation is found at Reynolds number 3000. This can be expected as this highly likely is in the transitional flow regime where laminar flow models no longer applies, and turbulent behavior is not yet applicable. The pressure drop model based on viscosity match using API recommendation underpredicts the actual dynamic pressure drop (ECD) in the laminar regime. This is in line with the observations in Figure 2 where match A shows a lower viscosity than the measurement values in the relevant shear rate region.

Conclusions

The set of experiments has shown that it is important that relevant shear rate measurements are used in detail to develop the Herschel-Bulkley model for drilling fluid viscosity. Optimal digital applications require relevant input values to provide acceptable accuracy.

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In order to fulfill the industry's vision to digitalize operations for automatization and remote controlling it is necessary to investigate and select input data properly. This also includes understanding the consequences from parametric studies in controlled environments as a supplement to field data.

References

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