LUBRICATION WITH WATER-BASED CLAY SUSPENSIONS

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ABSTRACT

The lubricating behaviour of a water-based rock drilling fluid (bentonite clay suspension) has been studied in a simple tribometer. Friction measurements were carried out with a model contact formed between a rotating shaft and a loaded planar counterface. The experiments were designed to investigate the tribology of the contact between the drillstring and the metal wall of an oilwell. Friction measurements were made for a range of loads and contact velocities and clay concentrations. The results are presented in the form of classical Stribeck-Hersey curves in order to identify the lubrication regime and to illustrate the combined effects of load and speed on the friction coefficient. Optical interferometry experiments were also carried out, using a ball-on-disc apparatus, in order to visualise the flow of the suspension through the contact. In a separate series of tests the interfacial shear stress of the mud formulations was measured for different contact metallurgies and operating conditions.

Two basic lubrication regimes are identified: at high loads a regime characterised by the deposition of layers of solid clay onto the contacting surfaces and at low loads, a regime in which the main lubricating action is provided by the base fluid. In the transition between the two regimes, an intermediate region is characterised by changes in the fluid composition and rheology within the contact. The general trend of the Stribeck curve is obtained and a peculiar scattering of the data is evident in the region between the boundary lubrication regime and the mixed lubrication regime. The intrinsic nature and the complex rheology of the fluid appear to be the parameters that may control this effect and in part define the lubrication regime.

LUBRICATION REQUIREMENTS IN OIL DRILLING

In oil well technology special fluids are used during drilling, completion and treatment operations. These fluids are in general complex multi-component dispersions or solutions and they are required to fulfill many different roles [1]. For example, pressure control in the wellbore, lubrication and cooling of the drill bit, removal of the cuttings from downhole locations and prevention of blowout. The fluids are formulated to have controlled rheological and tribological properties as these have a profound effect upon the overall drilling and well operation [1]. In modern drilling technology it is desirable to improve the conventional lubricating action of the mud since increasingly severe conditions are encountered in extended-reach oil wells. It is generally accepted that sliding friction between the drill string and either the metallic casing or the drilled strata causes torque and drag forces in directional wells. Friction coefficients can be estimated from field measurements and are generally in the range 0.1–0.4 [2]. In drilling applications it would be desirable to reduce the friction in order to reduce the energy dissipation and the wear of the drillstring, as well as the prospect of drillstring seizure and breakage. The current paper presents the results of an investigation of the lubricating behaviour of water-based clay suspensions in metal contacts. The study has been carried out experimentally using a commercial friction device modified to give a model-lubricated contact between a rotating shaft and a housing. Friction was measured over a range of rotational velocities and normal loads for different clay concentrations. An optical interferometry technique has been used to visualise the flow of the lubricant through the contact in order to provide a better understanding of the lubrication mechanism.

EXPERIMENTAL

The test lubricant was bentonite clay in water (2%, 3% and 5% clay weight fraction). The frictional behaviour was studied using a typical tribometer, which was modified in order to obtain a lubricated contact between the shaft and a planar metal counterface. Mild steel samples (4 x 4 cm) were used for the counterface and were loaded against a 25 mm diameter rotating mild steel shaft. The normal load was applied by means of dead weights ranging from 0.05 kg to 0.8 kg (maximum Hertzian measure ≈ 100 MPa) and the speed of the shaft was 0.2 to 0.9 m/s.
RESULTS AND DISCUSSION

The frictional force between the shaft and the counterface was measured for a range of loads and rotating speeds and as a function of time. Representative data is presented for the 2% mud composition where the friction coefficient is plotted against the normal load W for different speeds in Figure 1.

Figure 1 Friction coefficient as a function of the contact load, W (Newtons). Four contact velocities are shown.

The range of values of the friction coefficient is very large (between 0.05 and 0.4), suggesting that the contact works in the mixed lubrication regime and for the highest loads in the boundary lubrication regime. As is normally expected in lubricated metal contacts, the friction coefficient increases with increasing load and with decreasing sliding velocity. There seems to be a “transition” in the trend of the data at about 1.5 \(\div\) 2 N between the two regimes. It can be noted that, for loads higher than 1.5 N, the friction coefficient is more affected by the change in the sliding velocity.

The friction data can be better analysed if presented in the form of classical Stribeck curves (Figure 2). The curves were obtained by plotting the measured friction coefficient versus the group \(\eta U/W\), the product of viscosity and velocity divided by the load. This has been done for three different mud compositions, with clay contents of 2%, 3% and 5%. The data collapses fairly well onto a master curve for both high and low values of the ratio \(\eta U/W\) (regions I and III), while there is a quite substantial scatter for the intermediate values (region II). This might be due to the complex nature and rheology of the fluid that, under those conditions of load and speed, affects the entry of the particles and as a direct consequence the film formation and the overall lubrication process. This seems to be a particular type of starvation effect, not caused by the typical reduction of fluid inlet but by the intrinsic rheological nature of the fluid. In certain contact conditions (zone II), the clay particles do not continuously enter the contact area but are either squeezed to the side of the contact or they accumulate in the inlet as aggregates until they are sheared and pass through. This may cause the scatter of the data in the central portion of the Stribeck curves.

Figure 2 Stribeck-Hershey curves for two aqueous mud concentrations. Three regimes, I, II and III are indicated.

CONCLUSIONS

The results of this work can be summarised as follows:
1. The measured friction coefficients are in the range 0.1 \(\div\) 0.4, corresponding to the boundary lubrication regime.
2. From the analysis of the Stribeck curves and the film thickness measurements, three basic regimes can be identified. A regime which is essentially controlled by the deposition of clay layers onto the surfaces (at high loads and low speeds) and a regime in which the lubricating action is provided mainly by the based fluid. A transitional regime is identified when passing from high loads to low loads, characterised by a less predictable behaviour, due to changes in the contact fluid composition.
3. The issue of “starved” lubrication appears to be important for these fluids and reflects the fact that the entry conditions, and thus the rheology of the fluid, strongly affect the formation of the lubricant film.
4. The optical studies indicate that the system does not actually “starve” even at high speeds because the inlet appears to be always flooded. Rather, a sort of phase separation takes place when the suspension flows through the contact. At high speeds the particles are pushed to the side of the contact leaving a very thin and irregular film in the central region.

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REFERENCES

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