CHEMICAL AND PHYSICAL PROPERTIES

SECTION A8
LUBRICITY

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CABOT

VERSION 2 – 09/13

A8.1 Introduction

With the increase in extended reach and horizontal drilling, the need for low torque and drag factors is becoming more imperative. In turn, fluid lubricity is an increasingly important factor in choosing the optimum fluid for the operation.

Several different tools are available for measuring friction in the laboratory. Result quality varies a lot. Large or full scale laboratory equipment has been shown to provide the most accurate results.

The coefficient of friction (COF) is defined as the ratio of the static or kinetic friction force to the normal force. The metal-to-metal and metal-to-sandstone friction coefficients for formate-based fluids have been measured in the HLT Lubricity Tester at Westport Technology Center in Houston and in the BP lubricity testing rig in Sunbury. In addition to these large scale tests, tests have also been carried out on the Baroid Lubricity Tester, which is typically applied in the industry as a first-pass measurement.

Only the lubricity of the formate brines themselves are discussed in this chapter. The effect of adding lubricants to formate-based drilling fluids is discussed in Section B5, Compatibility with Additives.

A8.2 Lubricity tests from HLT Lubricity Tester

A8.2.1 Instrument description

The HLT Lubricity Tester at Westport Technology Center in Houston is a result of a Joint Industry Project between MI Drilling Fluids and BP Exploration to develop an instrument to measure the friction coefficient of drilling fluids under simulated field conditions. The instrument developed in the late eighties (Figure 1) is now jointly owned and operated by MI Swaco and Westport Technology Center International. Results obtained by the instrument have been verified with field data, and the instrument is considered today's industry standard.

The Lubricity Tester is supported on a lathe bed and is designed to measure the coefficient of friction of metal-to-metal, metal-to-sandstone, and metal-to-shale at temperatures up to 121°C / 250°F with pressure and variable torque under automated control.

Figure 1 Westport / MI Drilling Fluids' HLT Lubricity Tester.

A8.2.2 Test fluids and conditions

HLT lubricity tests were run on a series of potassium and cesium formate brine blends, varying in density from 1.60 to 2.28 g/cm^3 / 13.34 to 19.0 lb/gal [1]. Water was tested and used as a baseline measurement.

Testing consisted of:

- **Metal-to-metal:** The metal test bob is composed of carbon steel (Rockwell hardness C 37) and is 3 inches long and 2.5 inches in diameter. The metal insert is composed of a cut section of N-80, 4.5 inch tubing.
- **Metal-to-sandstone:** Metal-to-Berea sandstone (200 mD) contact
- **Metal-to-shale:** Contacts metal-to-Pierre II shale contact

Tests were carried out at temperatures of 24, 66, 93, and 124°C / 75, 150, 200, and 225°F. The cell pressure was 1.72 MPa / 250 psi.

A8.2.3 Test procedure

The HLT Lubricity Tester was calibrated with water. For all measurements, a contact of 150 rpm and 75 lbf was used. Each sample was circulated at a constant flow rate of 2 gallons/minute during each test. Each COF test was run using the test protocol of the HLT machine. Each test was a run of nine series, with 50 data points per series and an average of 25 readings per data point. The COF was determined as the average for each test.

A8.2.4 Results

Test results (Table 1) indicate that potassium and cesium formate brines and their blends are extremely lubricious, significantly reducing coefficient of friction (COF) values from that of water (Table 2). The average coefficient of friction values are also compared to water, with the percentage reduction shown.

Table 1 COF for potassium / cesium formate fluid blends, measured by the HLT Lubricity Tester and the Baroid Lubricity Tester.

Brine		Water	KCsFo 1.60 g/cm³ / 13.3 lb/gal	KCsFo 1.77 g/cm³ / 14.8 lb/gal	KCsFo 1.94 g/cm³ / 16.2 lb/gal	KCsFo 2.11 g/cm³ / 17.6 lb/gal	CsFo 2.28 g/cm³ / 19.0 lb/gal
Metal-to-metal							
24°C	75°F	0.3640	0.1391	0.1437	0.1446	0.1561	0.1227
66°C	150°F	0.3595	0.1745	–	0.1496	–	0.1526
93°C	200°F	0.3647	0.1963	–	0.1705	–	0.1661
107°C	225°F	0.3399	0.1802	–	0.1856	–	0.1857
Baroid L. M.		0.355	0.075	0.100	0.105	0.110	0.103
Metal-to-sandstone							
24°C	75°F	0.5209	0.1281	–	0.0944	–	0.1267
66°C	150°F	0.5299	0.1589	–	0.1303	–	0.1557
93°C	200°F	0.5267	0.1723	–	0.1313	–	0.1513
107°C	225°F	0.4970	0.1695	–	0.1318	–	0.1813
Metal-to-shale							
24°C	75°F	0.4524	0.1574	0.1442	0.1358	0.1588	0.1590
66°C	150°F	0.6276	0.2107	–	0.1854	–	0.2066
93°C	200°F	0.5859	0.2190	–	0.2459	–	0.2395
107°C	225°F	0.5750	0.2177	–	0.2587	–	0.2506

Table 2 Percentage reduction of COF from that of water for potassium / cesium formate blends, measured by the HLT Lubricity Tester.

Brine		KCsFo 1.60 g/cm³ / 13.3 lb/gal [%]	KCsFo 1.77 g/cm³ / 14.8 lb/gal [%]	KCsFo 1.94 g/cm³ / 16.2 lb/gal [%]	KCsFo 2.11 g/cm³ / 17.6 lb/gal [%]	CsFo 2.28 g/cm³ / 19.0 lb/gal [%]
Metal-to-metal						
24°C	75°F	61.79	60.52	69.98	57.12	66.29
66°C	150°F	51.46	–	58.39	–	57.55
93°C	200°F	46.17	–	53.25	–	54.46
107°C	225°F	46.98	–	45.40	–	45.37
Metal-to-sandstone						
24°C	75°F	75.41	–	81.88	–	75.68
66°C	150°F	70.01	–	75.41	–	70.62
93°C	200°F	67.29	–	75.07	–	71.27
107°C	225°F	65.90	–	73.48	–	63.46
Metal-to-shale						
24°C	75°F	65.21	68.13	66.00	64.90	64.85
66°C	150°F	66.43	–	70.46	–	67.08
93°C	200°F	62.62	–	58.37	–	59.12
107°C	225°F	62.14	–	55.01	–	56.42

Reductions are seen in the range of 46% to 66% (metal-to-metal), 63% to 82% (metal-to-sandstone), 55% to 70% (metal-to-shale). These low COF trends were seen at all test temperatures.

Comparison with water-based, oil-based, and synthetic-based drilling fluids, all formulated with lubricants, also confirms very low coefficient of friction for formate brines (Table 3).

Table 3 Coefficient of friction (COF) of various fluid types measured using the HLT Lubricity Tester.

Fluid	Metal-to-metal	Metal-to-sandstone
Water-based, 15.0 lb/gal[1)]	0.264	0.338
Diesel-based, various weights[1)]	0.180	0.223
Mineral-based, various weights[1)]	0.223	0.231
Synthetic-based, various weights[1)]	0.181	0.253
Potassium / cesium formate[2)]	0.162	0.144

1) Average COFs over several years measured with same instrument
2) Average COFs over all temperatures

A8.3 Lubricity tests from Baroid Lubricity Tester

The potassium / cesium formate blends above were also tested in the Baroid Lubricity Tester, according to API procedures. Test parameters were 60 rpm, metal-to-metal contact, 150 inch-lbs of torque. Each test was run for five minutes. The results from these tests are included in Table 1.

A8.4 Lubricity tests from BP Side Load Lubricity Tester

A8.4.1 Instrument description

The Sunbury lubricant test device is a small scale model of a drilling rig. The drill pipe is replaced with a 1" OD steel shaft that rotates inside of a 1 – 1/2" ID steel casing. The casing is supported on linear bearings and can be moved from side to side. The contact length of the casing and the shaft is 74.1 cm / 2.43 ft.

Side loads are applied via a pulley system on the casing so that the inside of the casing is pressed against the steel shaft. An air motor on the top powers the shaft. A torque transducer is mounted between the air motor and the shaft and records the torque. A tachometer monitors rotary speed.

The mud circulation system consists of a vessel with a volume of about 1.32 gal, which can be heated to 65°C / 149°F. The mud is circulated through the annulus from the bottom to the top.

A logging unit captures data from the rig (torque, temperature, and rotation speed).

A8.4.2 Test fluids and conditions

Testing has been conducted on various concentrations of all three formate brines [2] along with a series of other brines. The brines were diluted with deionized water.

A8.4.3 Test procedure

- Rotation speed 120 rpm (field condition)
- Pump rate: 1.89 gpm (7.12 liter/min). Equivalent to 500 gpm in the field. Variations were shown to have minimal impact
- Side loads: 31, 21, and 11 kg. Representative for true field conditions. Straight shaft was used (variations shown to have minimal impact)
- Temperature: All tests were run at standard temperature 25°C / 77°F. Heating caused by friction led to actual temperatures up to 30°C / 86°F)
- Duration: Each test was run for 15 minutes. This was found to give stable test results

The general procedure started with a two-minute run without any weights to find the 'tare torque'. A side load of 31 kg / 68.3 lbs was then applied for 15 minutes, followed by a two-minute break to re-establish the tare torque. The run was then continued with a side load of 21 kg for 15 minutes, followed by a two-minute break, and finally a side load of 11 kg for 15 minutes. Average COF was calculated based on the average of the three last minutes of each load.

A8.4.4 Test results

The results for the formate brines are shown in Figure 2 and Figure 3. As expected, the coefficients of friction for the individual formate brines are dependent on the concentration. At high concentrations, both potassium and cesium formate are as lubricious as oil-based muds measured in the same study. At lower concentrations, typically sodium formate and the lower sodium / potassium formate density range, formate brines will benefit from addition of a lubricant (see part B of the manual).

For all brine systems tested in this study, it was concluded that the lubricity of the brine could be best correlated to brine viscosity. The lubricity was found to be higher with increased brine viscosity. It is important to note that this relationship applies to the viscosity of the formate brine itself and not the bulk viscosity of the fluid. Therefore, simply viscosifying a formate brine will not necessarily improve its lubricity.

For cesium formate, particularly at a given density, lubricity of the potassium / cesium formate blend will be better than lubricity of a diluted cesium formate fluid.

References

[1] Spreadsheet "Friction Coefficient.xls", Westport Technology Center International.

[2] Pingitzer, G.: "Lubricity of Drilling and Completion Fluids – The Influence of metal type on friction", Master Thesis, University of Leoben, Austria.

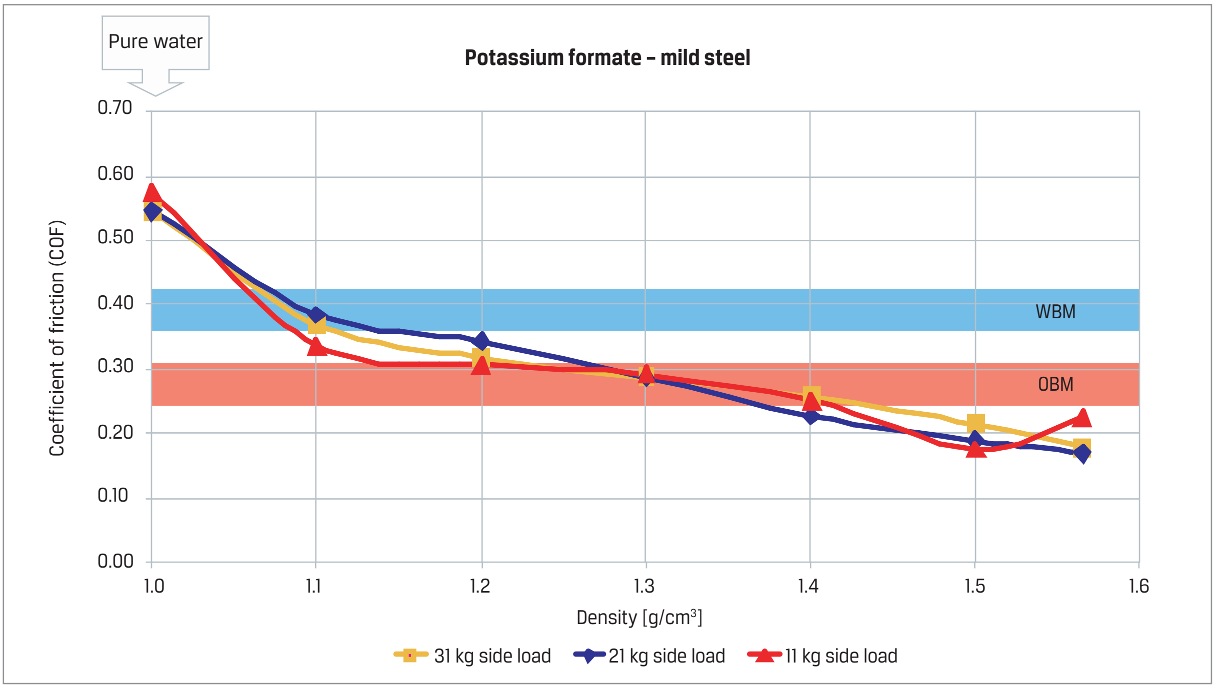

Figure 2 Metal-to-metal COF for potassium formate as a function of brine concentration for mild steel. Measurements are conducted using the Sunbury Lubricity Tester.

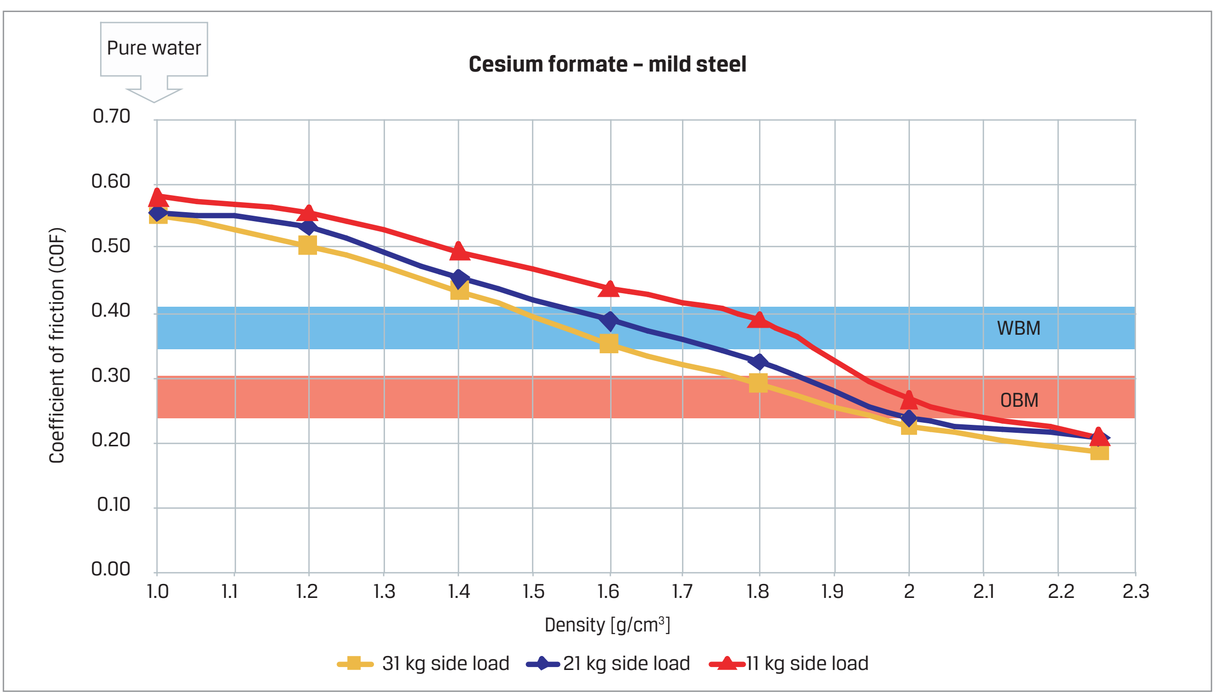

Figure 3 Metal-to-metal COF for cesium formate as a function of brine concentration for mild steel. Measurements are conducted using the Sunbury Lubricity Tester.