ABSTRACT

Huang, Pao-Tsung. Ph.D., Purdue University, May 2013. Rheological Properties and Lubrication Performance of Clay-based Drilling Fluids for Trenchless Technologies. Major Professor: Marika Santagata.

This study investigated the rheological and lubrication performance of water based bentonite clay suspensions used as drilling fluids in horizontal directional drilling (HDD), a trenchless technology widely used in the installation of underground utilities.

The rheological testing program was performed using a state-of-the-art rheometer, and included amplitude sweep, stress ramp, frequency sweep, and creep and recovery tests, to probe the behavior at rest and in flow of suspensions prepared with different commercial bentonite based materials. These tests mapped the effect of base clay material, solid content, water salinity, temperature, and the presence of select additives on key rheological properties including: storage/loss modulus, yield stress/strain, stress/strain at solid-liquid transition, and plastic viscosity. The results are interpreted in an integrated manner, utilizing a framework that is founded on an existing rheo-physical model, and fundamental knowledge of colloidal interactions and of the microstructure of clay suspensions. This interpretation is supported by direct observation of the microstructure of the clay suspensions with cryo scanning electron microscopy (Cryo-SEM).

The tribological investigation relied on a novel custom tribometer, which was designed, constructed and extensively validated as part of this study, and through which the lubrication performance of drilling fluids can be evaluated under field relevant conditions (normal stress level, speed and materials). The testing program included tests to measure the C.O.F. between HDPE (the most common material used for HDD pipes) and sandpaper of varying grit size (mean particle size, MPS=14 – 275 μm) to represent ground formations of different grain size; and between HDPE and laboratory prepared filtration mud cake samples. Both types of tests were performed with no lubricant, as well as using two different clay based fluids specifically designed for HDD. The first set of tests show that a reduction in the C.O.F. relative to the value measured under dry conditions is observed only with the finer sandpaper (MPS<60 μm), primarily through a mechanism of rolling lubrication due to the presence in the fluid of shale particles, with size (< 75 μm) of the same order of those of the sandpaper grains. Given the normal stress levels and speeds associated the installation of HDD pipes, pressure generation within the lubricant (hydrodynamic lubrication) possibly provides only a minor contribution to the reduction of the C.O.F., and only for the finest sandpaper (MPS=14μm). For larger grit size of the sandpaper (MPS≥60μm), neither mechanism is active, and no reduction in C.O.F. is observed with the application of the lubricant. The HDPE-filtration cake tests indicate that provided that the lubricant can be supplied at the interface, the C.O.F. can attain very low values (<0.1) proportional to the lubricant's viscosity. Much higher friction is observed when the HDPE is in direct contact with the filtration cake. Overall, the performance of the lubricant is inherently linked to the formation and the bulk properties of the filtration cake, which creates the conditions for generation of pressure within fluid, and controls the C.O.F. when the fluid is displaced from the interface.