Drilling Fluid Criteria for Pipeline Installation by Horizontal Directional Drilling, Part I

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The first of two parts. The second part of this paper will appear in the Winter issue of No-Dig Engineering.

ABSTRACT

Drilling fluid plays a key role in the installation of a pipeline by horizontal directional drilling and accounts for the majority of the associated environmental impact. An improper drilling fluid program can result in an unsuccessful pipeline installation or in damage to adjacent structures. This paper examines the functions and properties of drilling fluids used in horizontal directionally drilled installations. Criteria for the design of drilling fluids are proposed, and solutions to problems that can arise during construction as a result of an improper drilling fluid program are discussed.

INTRODUCTION

This article is an excerpt from a report entitled *Drilling Fluids in Pipeline Installation by Horizontal Directional Drilling, A Practical Applications Manual* produced under the sponsorship of the Pipeline Research Committee (PRC) of the American Gas Association (A.G.A.). The PRC's objective in producing this report was to increase the level of technical sophistication relative to drilling fluids used in the installation of pipelines by horizontal directional drilling (HDD). It is anticipated that this increase will benefit pipeline owners and contractors through reductions in HDD installation costs and environmental impact.

The functions of drilling fluids in pipeline installation by HDD, the behavior of soil and rock structures relative to drilling fluid flow, general drilling fluid criteria, and general solutions to drilling problems are discussed in this article. Criteria and solutions presented have been derived from experience in the HDD industry coupled with established practice in the oil well drilling industry. They have not been proven by studies in the laboratory or by analysis of formally recorded HDD jobsite data. Therefore, they are subject to revision. It is hoped that criteria presented here will serve as a starting point from which proven techniques can be developed.

The opinions, findings, and conclusions expressed in this article, as well as the full PRC report, are those of the author and not necessarily those of the A.G.A. Mention of a company or product name is not to be considered an endorsement by A.G.A. or J. D. Hair & Associates, Inc.

FUNCTION OF DRILLING FLUIDS IN HDD

The principal functions of drilling fluid in HDD pipeline installation are listed below.

Transportation of Spoil - Drilled spoil, consisting of excavated soil or rock cuttings, is suspended in the fluid and carried to the surface by the fluid stream flowing in the annulus between the hole and the pipe.

Cooling and Cleaning of Cutters - Drilled spoil build-up on bit or reamer cutters is removed by high-velocity fluid streams directed at the cutters. Cutters are also cooled by the fluid.

Reduction of Friction - Friction between the pipe and the hole wall is reduced by the lubricating properties of the mud.

Hole Stabilization - The drilled or reamed hole is stabilized by the drilling fluid. This is critical in HDD pipeline installation as holes are typically in soft soil formations and are uncased. Stabilization is accomplished by the drilling fluid building up a wall cake and exerting a positive pressure on the hole wall. Ideally, the wall cake will seal pores and produce a bridging mechanism to hold soil particles in place.

Transmission of Hydraulic Power - Power required to turn a bit and mechanically drill a hole is transmitted to a downhole motor by the drilling fluid.

Hydraulic Excavation - Soil is excavated by erosion from high velocity fluid streams directed from jet nozzles onto bits or reaming tools.

Soil Modification - Mixing of the drilling fluid with the soil along the drilled path facilitates installation of a pipeline by reducing the shear strength of the soil to a near fluid condition. The resulting soil mixture can then be displaced as a pipeline is pulled into it.

In addition to performing the functions listed above, drilling fluid used in an HDD installation should be environmentally benign and easily processed. Unusual equipment or long mixing periods should not be required. It should be relatively easy to maintain and control in the field.

SUBSURFACE BEHAVIOR

It is difficult to accurately visualize, or model, the subsurface behavior of drilling fluid during the various phases of an HDD installation. Soil conditions are inconsistent and random. Hole sizes will vary, and the path of the hole will be deviated. The pipe will not be centralized in the hole. It will bear on the top, bottom, or sides depending on its buoyancy, stiffness, and the shape of the hole. For certain soil conditions, an open hole may not even exist.

In order to rationally design the properties of drilling fluids, the interaction of the tools (reamers, bits, etc.), soil, and fluid must be described. Two models are proposed: the *Open Hole Model* and the *Fluid Model*.

Open Hole Model - The open hole model is similar to that used to describe behavior in an oil well. The tool has cut a cylindrical hole in the subsurface. Drilling fluid is flowing to the surface in the annulus between the pipe and the hole wall. A wall cake has been formed around the hole wall. Drilled spoil is transported in the drilling fluid to the surface. This model is generally applicable to clay soils and rock. It may also apply to silts and soils consisting of a mixture of clay with sand or gravel, depending on the density of the material, the specific make-up of the coarse fraction, and the binding or structural capacity of the fine fraction.

Fluid Model - It is probable that loose cohesionless soils, those consisting primarily of gravel or sand, will not support an open hole over a long horizontally drilled length. This does not, however, prevent the installation of a pipeline. The mechanical agitation of the tool coupled with the injection of bentonitic drilling fluid will cause the soil to experience a decrease in shear strength. If the resulting shear strength is low enough, the soil will behave in a fluid manner allowing a pipe to be pulled through it.

The fluid behavior of loose sands, commonly referred to as quicksand, is defined by geotechnical engineers as *liquefaction*. It is brought about by the fact that the sand possesses a *metastable* structure. It is stable only because of the existence of some supplementary stabilizing influence. A clean sand deposited under water is stable, although it may be loose, because the grains roll down into stable interlocking positions. A sand deposited simultaneously with silt may develop a metastable structure. The sand grains are prevented from interlocking in a stable structure by the interference of the loose silt surrounding them. (Terzaghi and Peck, p. 108).

In an HDD installation, the colloids in the drilling fluid will act as an interfering agent. Some drilled spoil may be displaced in the drilling fluid stream leaving a less dense soil structure in its place. However, annular flow will be inconsistent in subsurface material behaving as a fluid. The fluidized material may have some shear strength or a very high viscosity. Drilling fluid flow will be channelized along the drilled path or proceed along an established path in the subsurface.

Real World Conditions - In an actual HDD pipeline installation, it is rare that the subsurface material is consistent to an extent which will allow either model presented above to be applied to the entire drilled segment. A crossing may be placed in competent rock beneath a river. Nevertheless, overburden soils will probably have to be penetrated before the rock stratum is entered. A crossing installed in the lower Mississippi River flood plain may encounter clays, silts, sands, and gravels of varying relative densities in a relatively short distance.

Only the general character of the subsurface material will be known in advance of construction. Therefore, a drilling fluid should be designed to perform in both models. Adjustments to specific properties may then be made in the field to improve performance.

GENERAL DRILLING FLUID PROPERTIES

Density - High formation pressures will not be experienced in an HDD installation. Formation pressures will typically be equal to the ground water hydrostatic head; that is, 0.433 psi per ft of depth (8.34 ppg). Therefore, drilling fluid need not be weighted. Sufficient annular pressure will be maintained by the equivalent circulating density (ECD) of the drilling fluid (density plus pressure required to produce annular flow). High density muds will result in high annular pressures and may exacerbate problems with lost circulation.

A simple freshwater-based drilling fluid will have about 4 percent by volume of low density solids. This equates to a density of 8.85 ppg (0.460 psi per ft of depth) or about 37 lbs. of 2.65 specific gravity solids per barrel of fluid. About half of these solids should be composed of bentonite with the remainder being drilled spoil (Lummus and Azar, p. 62).

Solids control equipment should be designed to remove drilled spoil from the fluid to the extent practical. At best, this will result in a drilled spoil to bentonite ratio (DS/B) of about

1:1 (Lummus and Azar, p. 63). For the typical unweighted fluid used in HDD installation, the DS/B should not exceed 2:1 (Lummus and Azar, p. 63). The DS/B should be maintained at, or below, this level during all phases of an HDD installation.

Viscosity - Viscosity affects two important functions of the drilling fluid: 1) its ability to suspend drilled spoil, and 2) the pressure required to maintain flow. The viscosity must be high enough to allow spoil to be suspended and transported in the drilling fluid stream. However, if the viscosity is too high, increased pressure requirements may result in inefficient pumping operations, reduced annular flow rates, and high annular pressures.

High annular pressures will increase the equivalent circulating density and, as with high density fluids, may exacerbate problems with lost circulation. Additionally, solids removal at the surface may be difficult if viscosity is too high. This may lead to an increase in actual density compounding annular pressure problems brought on by high viscosity fluids. Therefore, viscosity should be optimized to a level which provides appropriate suspension properties while maximizing flow efficiency.

Viscosity should be controlled on the basis of field tested properties and observed performance. Varying soil conditions and operational phases involved with an HDD installation must be considered. There is no one value of viscosity which will provide optimal performance for all locations or even for all operations at a specific location. If clay soils are being penetrated, little or no viscosifier may be required to affect spoil suspension. Drilling may proceed with water. The native soil will go into suspension producing a viscous drilling fluid. Viscosity will increase on its own accord requiring the addition of water to preserve flow efficiency.

Soils consisting primarily of silt may also exhibit a tendency to go into suspension with clear water. More likely, these soils will require the addition of a viscosifier to aid in suspension. The viscosity will be less, however, than that required to suspend drilled spoil trending to the gravel end of the spectrum.

Flow efficiency may be more critical than spoil suspension in the reduced annular space involved with pilot hole drilling. It is unlikely that the gravel fraction of a stratum will be suspended in a long horizontal hole with an approximate 2-in. annulus regardless of the viscosity. Minimum annular pressures may also prevent lost circulation and the resulting inadvertent returns which are prone to occur during pilot hole drilling. Viscosity may become more important during prereaming when a large volume of spoil is being suspended and displaced.

However, it should be remembered that shear rates in the large annular spaces typical of prereaming operations are very low. Therefore, because of the non-Newtonian characteristics of drilling fluids, the actual viscosity in the annulus will tend to increase. A lower viscosity may be more effective during pipe installation. The quantity of drilled spoil to be suspended should be reduced if the drilled path has been prereamed. Flow efficiency is important. High annular pressures may increase drag through differential sticking.

Gel Strength - Gel strength affects the drilling fluid's ability to suspend drilled spoil when the fluid is at rest. This comes into play when pumping is suspended for connections, overnight shut down, or between passes. The gel strength may also be beneficial in stabilizing a path where circulation has not been maintained. The gel structure of the drilling fluid at rest may tend to maintain, or encourage, a metastable structure. However, high gel strengths can produce inefficient flow properties. Increased pressure may be required to regain circulation and high swab or surge pressures may be experienced when pipe is moved after a static period.

Filtration - The formation of a low permeability filter cake is necessary to maintain an open hole in an HDD installation. This is particularly true where the strata are trending into sands and gravels. The pressure differential across the filter cake aids in the stabilization of the soil.

Lubricity - Lubricity is important to the success of an HDD pipeline installation for two reasons. It aids in pipe installation by reducing the friction between the pipe and soil and may contribute to reduction in shear strength and associated fluidization of granular soils where an open hole is difficult to achieve. Lubricity should be maximized. However, the lack of a standard field test to gauge lubricity makes evaluation of this property in various fluids difficult. Care should be taken to insure that any lubricants added to a drilling fluid do not have an adverse environmental impact.

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