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

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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 article 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
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.

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DRILLING PROBLEMS

Lost Circulation
Lost circulation is prevalent in HDD pipeline installation. Most projects undertaken are completed with at least partial loss of circulation. This is due to the fact that the majority of installations are through unconsolidated, near surface, alluvial deposits. It should be recognized that subsurface conditions which preclude, or make very difficult, maintenance of circulation will exist at many HDD locations. Resources spent in an effort to maintain circulation should be weighed against the potential benefits achieved through full circulation. Nevertheless, maintenance (maximization) of drilling fluid circulation can be beneficial, if not imperative.

A lost circulation should not be confused with fluid loss. Lost circulation involves the diversion of “whole mud” along a flow path other than the annuli leading to the entry and exit points. Fluid loss involves the separation of water from the drilling fluid through the process of filtration.

Subsurface Conditions
For lost circulation to occur, there must be subsurface conditions which will accept whole mud. Examples of such conditions are listed below (Drilling Mud, p. 48):

- Cavernous and open-fissured formations such as karstic limestone
- Very coarse and permeable shallow formations such as loose gravel
- Naturally fractured formations such as fractured and jointed rock or clay
- Easily fractured formations

It should be noted that repeated experimental work has shown that whole mud cannot be forced into sand beds without fracturing (Drilling Mud, p. 48). Intuition indicates that lost circulation will be a greater problem in sand than in clays. However, random observations on HDD installations have demonstrated lost circulation occurs readily in naturally fractured (slickensided) clay and rock strata.

PREVENTATIVE MEASURES

The occurrence of lost circulation can be minimized in strata conducive to annular flow by adjusting drilling fluid properties and drilling practices to minimize downhole pressures. The drilling fluid flow circuit should be analyzed to establish hole dimensions, rheological properties, and flow rates which are, at least theoretically, conducive to annular flow. Rheological properties in the annulus should be measured in the field and adjusted as required to conform to the analyzed circuit.

General lost circulation prevention criteria are listed below:

- Minimize annular pressures by minimizing density and flow losses. Viscosity should be minimal consistent with hole cleaning requirements and stabilization.
- Minimize gel strength.
- Do not allow a plunger effect to occur from material bailing up on bits or pipe.
- Size the hole frequently to keep the annulus clean and unobstructed.
- Control penetration rates and travel speeds so that a plunger effect does not occur.
- Establish circulation slowly and before advancing when flow has been suspended.

In strata not conducive to annular flow, such as karstic limestone, jointed rocks and clays, or coarse gravel, preventative measures will not be effective.

Regaining Circulation — The first step in regaining lost circulation is diagnosis. A flow circuit analysis should be performed if one was not included in prejob planning. Geotechnical data should be reviewed to ascertain if subsurface conditions are conducive to annular flow. Measurements of
actual fluid properties in the annulus should be taken and compared with the theoretical flow circuit. If field conditions can be established which satisfy the requirements of the theoretical circuit, the hole should be sized to clear obstructions and establish flow. This may require several trips. Sizing operations should be conducted in accordance with the prevention criteria previously listed Suspending drilling activities for a period of six to eight hours may also aid in establishing circulation. Drill pipe should be withdrawn from the area of concern (Drilling Mud, p. 51).

If circulation cannot be established by adjustment of fluid properties and drilling practices, the conclusion may be drawn that a zone of material not conducive to annular flow has been encountered. This zone must be sealed to allow circulation to be established. The success of the sealing material will depend on the structure or porosity of the zone.

It may be possible to seal a porous granular material, such as gravel, using a high viscosity bentonite plug. The increase in solids in the plug fluid may tend to bridge between the soil particles and inhibit flow. Increased viscosity and gel strength will also inhibit flow into the zone just as it does in the annulus. The plug should be placed along the hole where the porous zone is suspected. The hole should then be redrilled taking care to utilize fluid properties and drilling practices which encourage annular flow. A waiting period, once again of six to eight hours, may be beneficial in allowing downhole pressures to dissipate and the bentonite plug to develop gel strength.

**Lost Circulation Material** — If a bentonite plug is not successful, lost circulation material may be utilized. There are many different conventional lost circulation materials designed for specific types of problems. If restoration of circulation is a priority and the measures presented in the preceding paragraphs are not successful, consultation with a specialist is warranted. Laboratory tests and field experience in the oil field have demonstrated that “engineered” blends of conventional lost circulation materials can exceed the performance of the individual components (Ali, Kalloo, and Singh, p. 199).

Additionally, development of new lost circulation materials is ongoing for oil field drilling applications. An example is the introduction of thermoset rubber as a lost circulation material. Laboratory studies have indicated that results achieved with this material surpass those achieved with conventional lost circulation material (Nayberg and Petty, p. 59).

**Inadvertent Returns** — Lost circulation may be accompanied by surface returns at an unanticipated location. Maintenance of circulation is the solution to inadvertent returns. Inadvertent returns can only be prevented to the extent that circulation can be maintained. However, inadvertent returns do not always accompany loss of circulation. When inadvertent returns occur, they should be contained, collected, and disposed of, or returned to the drilling fluid system.

**Stuck Pipe** — Stuck pipe problems on HDD installations can stem from several sources not related to drilling fluids. An obstacle may be encountered, such as a cypress stump, which lodges the pipe or tool. A highly deviated hole may cause a relatively rigid large diameter pipeline to “bind” as it is forced around a tight curve. The primary solutions to these problems involve basic remedial action (i.e., redrilling). Adjusting drilling fluid properties to increase lubricity may help free pipe which has become stuck because of an obstacle or tight hole. Nevertheless, the hole will probably have to be redrilled before the installation can be completed successfully.

**Differential Pressure Sticking** — Stuck pipe may also be caused by differential pressure sticking. Differential pressure sticking occurs when the pipe becomes embedded in the borehole wall. This causes a pressure differential to form between the pipe exposed to the borehole and the pipe embedded in the wall. The pipe sticks. When this occurs, a “spotting” fluid may be used to increase lubricity and allow the pipe to be pulled free.

Additionally, drilling activities may be suspended. As with lost circulation, this may be beneficial in allowing downhole pressures to dissipate thereby reducing the differential. Field experience has demonstrated that, in some cases, stuck drill pipe can be freed after it has been allowed to “rest” overnight. The theoretical basis for this is not clear, however, and suspending drilling activities should be employed with caution since problems with stuck pipe can increase over time.

**Spotting Fluids** — Petroleum oil-based fluids, particularly diesel oil, have been traditionally used as spotting fluids. For environmental reasons, petroleum oil is not suitable for use on most HDD installations. Environmental concerns have prompted service and chemical companies to undertake development of low toxicity water-based spotting fluids that would be acceptable substitutes for conventional oil-based systems. Many of the new fluids are glycol or glycerol based systems (Clark and Almqquist, pp. 126, 127). Tests have shown glycol based systems to have low toxicity (Bland, p. 58). Studies have indicated that environmentally acceptable spotting fluids can be as effective as diesel oil (Darley and Gray, p. 413) (Clark and Almqquist, p. 128).

For spotting fluids to be effective, their application must be properly planned and executed. Consultation with a specialist is warranted in diagnosing the cause of stuck pipe as well as determining a plan of action. A specialist will also be able to assist in determining if use of a specific spotting fluid in a specific location will violate environmental regulations.

**Soil Chemistry** — Drilling fluid properties can be affected by the chemistry of the soil which is being penetrated. Examples of soil chemistry problems and solutions are described in the following paragraphs.

**Peat** — The association of drilling fluid with peat can have an adverse effect on drilling fluid properties. The presence of lignites in the peat may cause a reduction in drilling fluid viscosity. This problem can be corrected by adding more viscosifier (bentonite). Another problem that can be encountered is a drop in the pH of the drilling fluid due to the low pH of peat. In order to minimize corrosion, the pH of the drilling fluid should be maintained between 9 and 10, a level at which little to no corrosion takes place. Drilling fluid pH can be raised by adding soda ash or caustic soda. When using caustic soda, care should be taken in handling the product and treating the mud. Caustic soda is a very strong base, and over-treatment will result in a very high viscosity.

**Clay** — Penetration of clay layers may cause the drilling fluid viscosity to increase to an undesirable level as the native clays go into suspension with the fluid. Additionally, some clays may exhibit a considerable swelling tendency. This can be a cause of stuck pipe. Viscosity increase can be reduced by adding thickeners. When clays are anticipated, viscosifier content in the fluid should be reduced. Some clays can be drilled with straight
water. Utilizing a fluid of bentonite and CMC (Carboxymethyl Cellulose) will generally provide adequate protection against clay swelling.

**Saline Soils** — If salt is present in the soil or ground water, it will have a negative impact on bentonite drilling fluid. The bentonite will tend to flocculate and drop out of suspension. Attapulgite may be used as a viscosity modifier. However, this has met with limited success on past HDD shore crossing projects where fresh water was not available. Bentonite drilling fluid that is fully hydrated in combination with CMC offers a solution to this problem. Full hydration is accomplished by letting the fluid stand (at least overnight) after mixing or mixing with high shearing forces (i.e., using a turbine mixer). The chloride content of the fluid should be checked regularly. If it exceeds 600 ppm, more fresh water fluid should be added.

**CONCLUSIONS**

Drilling fluid properties are critical to the success of an HDD installation. Establishing criteria for HDD drilling fluid requires an understanding of the role it plays during the various phases of installation. Long established practices taken from the oil field may be useful but may not be applicable for every operation and subsurface condition encountered on HDD pipeline installation projects. The key to success lies in accomplishing three tasks:

1. Establish, before construction, a program which sets out fluid properties going into and coming out of the hole for each phase of operations and for each anticipated subsurface condition.
2. Monitor, during construction, actual fluid properties going into and coming out of the hole for each phase of operations and for each anticipated subsurface condition.
3. Adjust drilling fluid properties to optimize performance or solve problems.

**REFERENCES**


Principles of Drilling Fluid Control (Twelfth Edition) Courtesy, Petroleum Extension Service (PETEX), The University of Texas at Austin.

