Horizontal Directional Drilling Information Guide

STRAIGHTLINE®

Drilling Fluid

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www.straightlinehdd.com

800-654-3484
620-802-0200 Intl

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CONTACT INFORMATION

Mailing address:

Finco, Inc.
PO Box 47
Yoder, KS 67585-0047

Phone:

800-654-3484 Toll free US and Canada
620-802-0200 International

Physical address:

1816 E. Wasp Road
Hutchinson, KS 67501

Web:

www.straightlinehdd.com
sales@straightlinehdd.com

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Glossary of "Mud" Terms

Bit balling Soil sticking to the drill bit, forming a ball.

Free water Makeup water that is squeezed out of the drilling fluid (see water loss).

Gel strength Denotes the carrying capacity of the drilling fluid, or its ability to suspend and carry solids through the bore tunnel.

Hydrate Process of bentonite platelets absorbing the makeup water.

Makeup water Water to which bentonite and polymer products are added to form the drilling fluid.

Marsh funnel A conical-shaped funnel, fitted with a small-bore tube on the bottom end through which mud flows under a gravity head. A screen over the top removes large particles that might plug the tube. Hallan N. Marsh of Los Angeles published the design and use of his funnel viscometer in 1931.

Viscosity A measure of the thickness of the drilling fluid. Viscosity is determined by time in seconds that it takes for one quart of drilling fluid to pass through a Marsh funnel.

Water loss Process of makeup water being squeezed out of the drilling fluid and forced out into the formation. Measured with a filter press.

Yielded Bentonite platelets have become fully hydrated.

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Introduction

Hallan N. Marsh of Los Angeles published the design and use of his funnel viscometer in 1931. A forward-thinking mud technologist in his day, Mr. Marsh stated in his 1931 AIME paper:

"The subject of mud sounds so simple, uninteresting and unimportant that it has failed to receive the attention that it deserves, at least as applied to the drilling of oil wells. As a matter of fact, it is one of the most complicated, technical, important and interesting subjects in connection with rotary drilling".*

While Mr. Marsh's comments were made in connection with the oil well drilling industry, the sentiment he expressed can easily be carried over to HDD. As we will discuss, drilling fluid is a vital component to the efficiency and effectiveness of any ground boring operation, impacting profits and contractor success in a way that demands attention.

A. Soil

A proper drilling fluid design discussion has to start with at least a basic understanding of soil composition. Some would say that soil is just the dirt beneath your feet, but for HDD purposes it is important to have a more in-depth understanding of what "dirt" consists of and to distinguish between soil types in order to effectively conduct a bore.

There is no such thing as "standard" soil. Soils vary throughout the globe, throughout the country, throughout the region and even the immediate area on which you are standing. If an HDD bore is to be 400 feet long, the soils at the front end of the bore may be quite different from the soils encountered along the way and at the exit end of the bore.

Soil is primarily composed of rock that has weathered in various chemical and physical ways so as to produce a broad range of particle sizes and chemical compositions. Concentrations of these particles allow us to identify the soil types by their characteristic properties. Although some HDD bores are conducted in solid rock, the majority occur in sedimentary soil primarily composed of clays, sands, calcite, silt, rock fragments and organic material. There are still several grades of each of these soil types, all behaving somewhat differently with respect to fluid absorption and retention. Our goal here, though, is to broadly discuss drilling fluid design as a general practice.

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* Marsh H: "Properties and Treatment of Rotary mud," Petroleum Development and Technology, Transactions of the AIME (1931): 234-251.

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B. Drilling Fluid Uses

A critical success factor for HDD operations is to maintain control over the hole. Since drilling fluid provides cooling for the drill head locating transmitter, as well as lubrication and stability to the bored hole, it is indeed a tool, as much as the drill itself. Properly designed drilling fluid helps the contractor to install the utility product as safely and efficiently as possible.

Effective drilling fluid design is a combination of a clear understanding of its use, its components and the purpose of each, and practical field experience in your specific conditions.

1) Dry Boring

Though rare, there are occasions when a bore can be made without fluids. However, when drilling in sand or clay, dry boring can result in the drill string overheating due to friction, resulting in damage to the drill head or transmitter and, ultimately, failed bores.

2) Boring with Water Only

a) In Sand

Drilling in sand will not work with water alone. Water filters out of the tunnel and into the formation as fast as you can pump it into the hole and will cause the formation to collapse downward and settle around the rods. Once this happens in a sandy condition, there is rarely any amount of horsepower that can overcome the weight of the earth and extract the drill string.

b) In Clay

Clay will tend to absorb water like a sponge, similar to a bentonite platelet. In time, the clay will absorb the water and swell to the point where it is contacting the drill pipe, tools and utility. This is typically worst near the entrance point of the bore because that is where the water has had the most time to filter into the clay. When this happens during pullback, a driller will typically start to experience increased rotary pressures (torque) and think he is having trouble turning the reamer. The fact is he is fighting surface tension placed on the drill pipe toward the front of the bore. Over time, this condition can result in getting the drill string totally stuck as well as causing damage to the utility being installed.

3) Why Use Drilling Fluids?

Properly prepared drilling fluids offer several benefits to boring operations:

- Inhibits clays and shales
- Suspends solids
- Stabilizes the bore hole
- Controls water loss

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- Reduces “bit-balling”
- Reduces rotary torque
- Reduces friction on drill pipe and utility
- Increases drill rig performance and life
- It’s the cheapest possible insurance
- Makes Money!

The following sections discuss how these benefits can be achieved.

C. Drilling Fluid Components

Bentonite, polymer, water conditioner and water are the four major ingredients typically combined to make drilling fluid, or “mud”. Understanding the nature and characteristics of these components is key to designing effective mud for a specific application.

1) Bentonite

Bentonite is a clay derivative. The word clay describes a natural material that tends to bind with water and is used to make products from china to bricks. There are over 50 types of clays in nine distinct categories. All have different reactions to moisture. Some clays remain plastic like modeling clay while others, like illite, will absorb large amounts of water and get you stuck.

Bentonite is derived from deposits of sodium montmorillonite clay, which in the United States is generally mined in Wyoming. Bentonite has a chemical construction of tightly bound minute flat plates. *If the individual plates from one cubic inch of bentonite were separated and laid edge to edge in a single plane they would completely cover sixty-six football fields.*

Strong agitation in slightly alkaline water causes the clay plates to separate (a process called shearing) and re-bond with the water molecules between the clay plates. The absorption of the water into the bentonite plates allows the bentonite volume to increase 15-fold. These shingle-like plates are kept in suspension through ionization, and cause the viscosity of the fluid to increase when fully separated, the process called yielding.

Fully yielded bentonite inside of a pilot bore or reamed tunnel section seals the tunnel by moving to the porous areas as a result of the pressure of the fluid trying to escape. With properly prepared fluid, the clay plates remain parallel to each other in the solution and create a very thin waterproof coating of clay inside the tunnel. The overlapping layer of clay plates attached to the inside of the tunnel is called the filter cake. The filter cake helps stabilize the bored hole, and significantly reduces water loss.

In addition to building a filter cake and controlling water loss, bentonite also adds suspension characteristics to the drilling fluid, sometimes referred to as gel

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strength, or the ability to suspend and carry solids out of the tunnel. Gel strength is normally a function of viscosity, but can also be enhanced by the addition of certain polymers.

Bentonite is used to control all types of unstable and non-compactable formations such as sand and gravel. It is also useful in managing sloughing clays and loams, which produce cuttings that are free from the formation. Bentonite will seal the hole and provide the gel strength required to move the solids out of the hole.

In HDD, there are generally two types of bentonite used. The first is a beneficiated bentonite product, generically called “hi-yield”. When beneficiated bentonite is processed, a special short chain polymer is added to enhance its water absorption qualities. While pure bentonite will yield approximately 3,360 gallons of drilling fluid per ton, beneficiated bentonite will yield approximately 8,400 gallons per ton. Though beneficiated bentonite is somewhat more expensive than the pure form, the cost difference is generally more than justified by the higher yield, making it the most commonly used in HDD operations.

The second type of bentonite commonly used in HDD operations is a “one-sack-mix” product. One-sack-mix products contain water conditioners that reduce the need for pH testing and water conditioning before mixing. Therefore, the operator can theoretically introduce the product into the mixing system, allow it to yield, and continue drilling more quickly. In practice, the operator should still test pH before and after mixing the first batch is mixed to make sure it is an acceptable range.

2) Polymers

Polymers are natural, modified natural, biologic or synthetic chemicals that are found in a wider range of products than are clays. Everything from ice cream to the rubber bumper on your new car depends on polymers for a variety of characteristics. Natural and modified polymers such as starches, cellulose, xanthium and guar gums have been used since ancient times to build viscosity and add lubricity to water, and their use in drilling fluids go back many years.

These compounds are in many organic chemical compositions but all are of a chemical bond type called chains**,** which refers to the way the individual molecules link together. Polymers are classified by the chain’s shape and the number of repeating chains. The type of chain is what causes different polymers to have different effects on drilling fluids.

Polymers can be used by themselves but are generally used by adding them to a base drilling fluid consisting of conditioned water and hi-yield bentonite, which is already mixed and yielded to the desired viscosity. Polymers are added to inhibit clay and shale, add lubricity, prevent bit balling, build viscosity, and control water loss, depending on your specific conditions.

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When used alone, the amount of bentonite required to achieve adequate water loss control can produce a drilling fluid that is too thick to pump, and it forms a thick unstable wall cake, which will cause high drag during the pullback. The remedy for this is to add a PAC polymer product that will reduce the water loss and simultaneously reduce the amount of bentonite required to control the borehole.

a) Applying Polymers

PHPA polymers are clay and shale inhibitors. These polymer chains readily attach themselves to clay or shale, sealing off the formation so that the *makeup water* cannot filter into the formation and cause it to swell. Adding PHPA polymer to the makeup water produces a noticeable increase in viscosity and lubricity. These polymers are frequently used without bentonite for drilling small diameter holes in compactable formations and as an additive to bentonite to increase viscosity and lubricity.

PAC polymer is used to control water loss. Its use as a drilling fluid is nearly always done in combination with bentonite. Besides preventing water loss, it also improves lubricity and helps to prevent bit balling. This product significantly improves the performance of drilling fluid in non-compactable conditions. By controlling water loss and increasing lubricity, bentonite enhanced with a PAC polymer reduces torque, thrust and the mud volume required to successfully complete the bore.

3) Water Conditioners

For most mini-HDD operations, water for the drilling fluid is drawn from a city hydrant, and the pH level tends to run between 5 and 7. To increase the pH to the desired range of 8 to 9, soda ash is typically added as a water conditioner.

4) Water

The pH of the makeup water plays an important role in how well and how quickly the chemical reactions take place that are required to produce good drilling fluid. Water pH should be tested and adjusted as required to the range of 8 to 9 before adding bentonite or polymers.

D. Mixing and Testing

1) Steps to Properly Mix Drilling Fluid

1. Check pH of the makeup water.
2. Add soda ash as required to adjust pH to between 8 and 9.
3. Introduce bentonite through a jet/venturi-style mixer.
4. Allow the bentonite to yield.
5. Check viscosity.

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6. If viscosity is too low, repeat steps 3 – 5.
7. Add polymer as needed.

2) Drilling Fluid Testing

a) pH

pH is the measure of how acidic or alkaline something is. The pH scale ranges from 0 to 14, where a mid-scale value of 7 is neutral. Less pH is acidic, and more is alkaline. For the drilling fluid purposes, a pH level between 8 and 9 (slightly alkaline) is ideal.

Test kits are readily available in a variety of styles, from simple litmus strips to electronic meters, and can be purchased at most hardware and pool supply stores.

A proper pH level allows bentonite to *yield faster*, *yield fully*, and *remain in suspension*. The pH level also affects the yield of PHPA polymers.

Yield faster – proper pH causes the bentonite plates to absorb the makeup water at the highest possible rate. That can translate to less time spent mixing and yielding, and more time drilling.

Yield fully – proper pH maximizes the yield. As stated earlier, a beneficiated bentonite plate can grow up to 15 times its original size. Makeup water pH heavily affects that growth. Poor water condition will retard the growth of the bentonite plate by 5 or 10 times. Proper pH adjustment maximizes yield, which reduces the amount of bentonite needed to achieve a specified viscosity. This, in turn, lowers drilling fluid costs.

Remain in suspension – on HDD jobsites, you may observe the bentonite separating, or settling out in the tank. Intuition may say that the mud needs to be stirred or agitated to overcome this problem. The fact is bentonite separates from the makeup water when the pH level is wrong. If it separates in the tank, it will separate in the hole. Therefore, proper pH level is also important to keep the drilling fluid in a homogenized state and deliver the sealing and carrying capacity you are paying for.

b) Viscosity

Viscosity is the measure of a fluid's resistance to flow. A basic test for all drilling fluids is the Marsh Funnel Test for viscosity. This test simply measures the amount of time it takes for a measured volume of drilling fluid to pass through a calibrated orifice.

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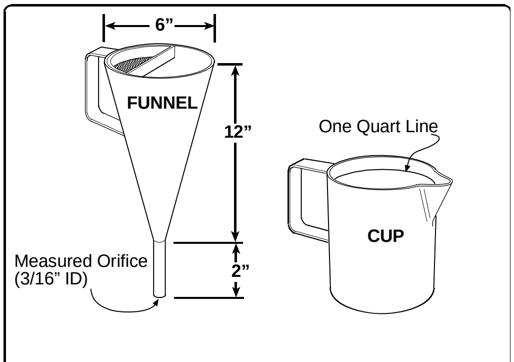
Drilling Fluid

To perform a Marsh Funnel Viscosity Test:



Marsh Funnel Test for Viscosity

1. Place your finger over the orifice at the bottom of the Marsh Funnel, then fill the funnel with drilling fluid by pouring it through the screen on the top of the funnel until the fluid reaches screen level.

NOTE: A common mistake is to put just 1 quart of the drilling fluid in the funnel instead of filling the funnel. This will result in a viscosity reading that is greater than actual.

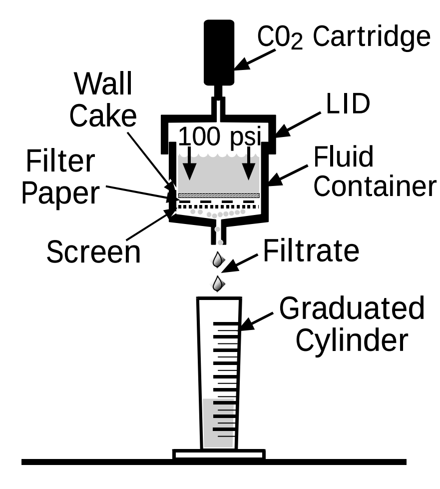
2. Place a 1-quart test cup under the funnel.
3. Simultaneously start the “timer” while removing finger from funnel orifice to allow fluid to flow into the test cup.
4. Stop the “timer” when fluid level reaches the 1 qt. line in the test cup.

Test Results: The amount of time (in seconds) that was required to flow one quart of the fluid is the measure of the fluid viscosity. For example, if fluid flowing from the funnel reached the 1-quart line in 50 seconds, then the fluid is said to have a “50 viscosity”. If 70 seconds had been required to flow the same volume of fluid, it would be described as 70 viscosity (or 70 second) fluid.

c) <u>Water Loss</u>

The test for water loss requires a special device called a filter press. In this test, a sample of mixed drilling fluid is pressurized into a special filter paper, which traps the fluid solids. Any liquid that can migrate through the solids, or wall cake, and filter paper over a specific length of time is captured and measured. The captured liquid is called “filtrate”, and is an indication of how resistant the tested batch of fluids will be to water losses in the bore tunnel. An examination of the trapped wall cake also indicates how well the tunnel will seal, and how vulnerable the tunnel walls may be to cave-in and swelling.

Water Loss Test



To perform a Water Loss Test:

1. Pressurize the test container @ 100 psi for 30 minutes.
2. Measure the filtrate (water loss) in cubic centimeters.
3. Remove and examine the wall cake.

Alternatively: Pressurize for 7.5 minutes then multiply filtrate results by 2.

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E. Designing Drilling Fluid for Various Soil Conditions

The following information provides some general guidelines on designing drilling fluid. It is important to note that this information serves as a baseline from which to start. In practice, careful notes should be kept regarding water pH, bentonite type, amount and viscosity, and polymer type and viscosity rise. The drill operator should also monitor feed rate and rotary and thrust/pullback pressures, while other crewmembers periodically observe the returns. The drilling fluid mixture can then be refined to provide the desired characteristics for the specific bore while keeping these pressures as low as possible.

1) Clay

In pure clay, it is common to use water with PHPA polymer as the drilling fluid. The more pure the clay formation and the more cohesive its characteristics, the better this combination tends to work. However, if hole enlargement by cutting rather than compaction is being done, then the cuttings and fine particles need to be suspended and carried out of the hole. Under these conditions, a base bentonite mix of 40 viscosity, plus PHPA polymer, will improve hole control.

2) Clay Loam

When drilling in clay loam, defined as a mix of clay and sand, where clay is the dominant element, a base bentonite mix of 40 viscosity plus a 10 viscosity rise with a PHPA polymer is a good mix to use. A bore conducted in clay loam will produce fine particles and small cuttings. The bentonite will suspend the fines and small cuttings and carry them out of the hole, while the polymer will inhibit the clay, preventing shrinkage of the bore tunnel opening, and provide lubricity, reducing surface tension on the drill pipe, tools and utility being installed.

3) Sandy Loam

When the conditions change toward a more sandy loam, the base bentonite viscosity should be raised to 50 and the polymer should be PAC instead of PHPA, as the higher sand content will free itself from the formation and require increased suspension characteristics in order to be carried out of the hole.

4) Sand

When conducting a bore in mostly sand, use a 50-viscosity bentonite base with a PAC polymer product. Add enough polymer to raise the viscosity of the mix by 10 points. This will provide good suspension characteristics, develop a tough, thin filter cake, and control water loss into the sandy formation.

5) Aggregates

As the sand increases into gravel and small aggregates, the viscosity of the drilling fluid must be raised in order to effectively suspend the cuttings.

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The chart below illustrates a guideline from which to develop drilling fluids for the soil conditions listed (amounts shown are per 300 gallons of water).

Mix per 300 Gallons

Soil Type	Desired Funnel Viscosity	High-Yield Bentonite	PAC Polymer	Liquid Polymer (PHPA)
Clay	40-45	1 – 1.5 Sacks		1 qt. +
	40-45	When drilling with polymer only		2-3 qt.
Clay Loam	40 - 45	1 to 1.5 Sacks	2 qt. or ➔	1 qt.
Sand Loam	50-60	1.5 to 2 Sacks	2 qt.	
Sand	55-65	2 to 2.5 Sacks	2 qt.	
Aggregate	65+	2.5+ Sacks	2 qt.	

F. The Properly Prepared Hole

A properly prepared bore tunnel has the following characteristics:

- **D**rilling fluid and cuttings can freely flow through the annular space.
- **T**he tunnel wall is stable because of applying the proper drilling fluids.
- **T**he drill string moves freely in the hole.
- **O**nce pulled into the hole, the product can easily slide back and forth.

G. Drilling Fluid Equipment

Easily as important as the characteristics of the fluid itself is the fluid management system. The components of a basic mud delivery system are storage and mix tanks, bentonite induction and mixing system, a supercharge pump, and a delivery pump.

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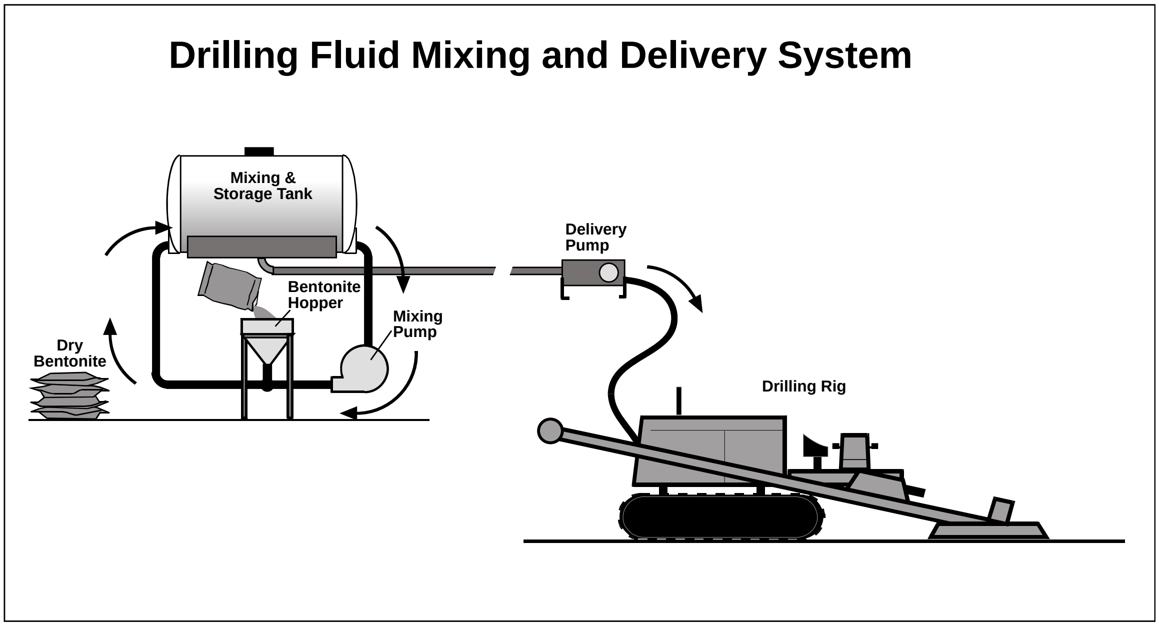
Drilling Fluid



- **Storage and Mix Tanks** - These are generally polypropylene tanks, and come in all shapes and sizes. Depending on the size of the drill and bore, there may be one or more tanks involved. Important aspects of the tank configuration chosen are how well it can keep up with mud demand during the bore and how easy it is to clean the system out when the job is over.
- **Induction and Mixing System** - Shearing bentonite at induction to the system is a major factor in how well the mud performs and how long it takes to mix the batch. Highly effective systems include a high-volume, low-pressure pump combined with an induction method that shears the bentonite as it enters the fluid stream. Less effective systems rely on swirling or stirring the mixture to achieve shearing, which is more time consuming and may result in lower performance fluid and increased bentonite consumption. The system should also be capable of circulating the mixed fluid rapidly enough to prevent bentonite settling.
- **Supercharge Pump** - The mix pump may also provide supercharged fluid to the mud delivery pump, or a second pump may be employed, depending on the mud volume required in a given time. Either way, the purpose is to prevent the mud delivery pump from starving for fluid or introducing cavitations in the pressurized fluid stream.
- **Mud Delivery Pump** - Final delivery of the mud to the drill string is accomplished with a high-pressure, low-volume mud pump, typically delivering fluid at pressures ranging from 200 to 1,500 PSI. Good bore planning will determine the actual amount of fluid required for the drilling or reaming tool to develop a proper hole. The mud pump

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should then be sized to deliver the desired amount and pressure of fluid while operating at about 350 RPM.

For many drilling operations, a basic system is all that is required. In applications where high fluid volumes are required such as in hard formation drilling, large diameter holes, or coarse conditions like gravel, the addition of one or more of the following items may be required to maximize production in the specific condition:

- **Mud Cleaning System -** These systems allow the contractor to pick up the spoils from the entrance and exit pits and return them to the cleaning system for processing and reuse in the drilling operation.
- **Auxiliary Mud Delivery Pump -** It is possible that the output capabilities of a drill's on-board mud pump may be inadequate in either pressure or flow to maintain control over the hole, or to perform at all in certain conditions. At this point, the addition of an auxiliary mud delivery pump will extend the capabilities of the drilling system.
- **Vacuum Truck or Trailer - As** spoil volumes increase, it is necessary to pick up the spoils, either for discarding at an approved location, or for recycling them through a cleaning system.

Summary:

Effective drilling fluid design is a combination of a clear understanding of drilling fluid components and the purpose of each, combined with practical field experience in your specific conditions. Properly designed mud will let you accomplish more with your rig than you ever thought possible and gain a huge competitive advantage over the contractor who thinks more power is the only solution. Remember: drilling fluid is an effective HDD tool.

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