Drilling Fluids
Effective & Powerful

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*Ian's work in the field of Exploration Diamond Drilling (EDD) is powered by "**iideas**" (Independent Innovative Drilling Engineering Applications and Services), including "Compleat Borehole Rescue," "Compleat Contracting," "Compleat Explorer" and "Compleat Driller" solutions.*

Simplifying Systems

More than 4,120 drilling fluid chemical products are listed in a recent O&G magazine supplement[i], contributed by 90 of the major chemicals service providers. That's an average of over 45 fluids products per supplier, with a bewildering array of trade names and materials descriptions and functions.

Exploration diamond drilling (EDD) is different; drilling fluids are much simpler and don't demand great sophistication largely because the drilling geometry, processes and downhole conditions are different to other types of rotary drilling.

Simplifying factors include:

- Very high rotation speeds for impregnated diamond bits (less for surface set crowns but still significantly fast)
- Very fine drilled cuttings or detritus are generated, that are easily moved up the narrow annulus in a flow of water – enhanced rheological properties are not required for this purpose
- Very seldom encounter pressured fluids or gases in the rocks being drilled – therefore weighted or densified drilling fluids are unnecessary

- Hard rock drilling encounters very little connected primary rock porosity – therefore fluid loss by filtration at borehole wall requires no special adaptation.
- Low to moderate rock temperature gradients mean that it is unnecessary to use high temperature resistant fluid systems
- Most hard rocks drilled do not contribute towards drilling fluid viscosity, and therefore no special thinning or dispersion agents are required to maintain rheological control. In most cases, EDD drilling fluids are constantly being thinned by the removal of cuttings before recirculating the fluid

Whilst the simplifying factors reduce the necessity for complex and sophisticated drilling fluid properties, there are several other factors that are much more specific to the development of useful drilling fluids for exploration diamond drilling. This includes the following:

- Diamond drilling involves high energy processes at the bit, and the demand for cooling and cleaning are significant. Water flushing through the bit is a limitation that can be surmounted by enhancing the wetting and cooling (heat transfer) properties of the drilling fluid.
- Heat and chemically altered hard rocks can display tendencies to "decompose" and collapse or cave
- Clay bearing rocks (especially those containing smectites) are prone to water sensitivity, resulting in stickiness, significant swelling, and possible micro-fracture and caving.
- High speed rotation of the drill rods (drill string) creates significant friction and torque – lubrication of the drill string is therefore a major function that the drilling fluid can perform.
- Similarly, high speed rotation, combined with compression of the lower portion of the drill string creates conditions conducive to the development of various kinds of vibration. Enhanced drilling fluid viscosity and lubricity, combined with drilling process controls, can be used to overcome vibration problems.
- Fractured and fissured rocks often display a tendency for the loss of whole drilling fluid, known as lost circulation; in this case engineered fluids that can resist circulation losses can play an important role.

The diamond drilling process is very demanding, and performance of a drilling fluid may be somewhat subjective – especially when clear cut performance measurements are not readily available. An experienced driller will be able to rapidly determine clearly indicate when a drilling fluid additive has performed the stated function(s) and achieved its purpose.

Drilling fluids products (alongside other drilling products) are largely marketed based on performance. But what performance is required or demanded? What are the most important measures?

Functions

Bearing in mind the abovementioned simplifying factors and the more specific demands for exploration diamond drilling, we can review the conventional functions of a drilling fluid. These classical functions are often cited as reference points – anyone who has attended a "mud school" or "drilling fluids course" would have heard them. In my opinion, these classical functions need to be rearranged and adapted for use in exploration diamond drilling.

My working list of functions for EDD drilling fluids is as follows:

1. Cools and cleans the diamond bit and reaming shell
2. Lubricates the core barrel and drill rods to:
    a. Reduce torque, rod chatter, and dampen drill string vibrations
    b. Condition the borehole and enable drilling to proceed at high rotary speeds
    c. Protect the drill rods and reduce excessive wear
    d. Minimise corrosion of the down hole equipment
3. Clears cuttings from the working face of the bit and carries them to the surface
4. Provides information to the driller on "Down-the-Hole" conditions
5. Releases and deposits drilled cutting or detritus in the settling pits
6. Facilitates the drilling and core recovery, especially in friable rock formations
7. Improves borehole stability and maintains borehole condition by:
    a. Stabilising formations that are water sensitive or liable to swelling, decomposition, caving and washing out
    b. Supporting broken formations through hydrostatic pressure
8. Facilitates borehole logging (e.g. caliper, gyro, gamma, resistivity, etc)
9. Provides buoyancy to the drill rods and casing
10. Provides some resistance to "lost circulation"

To be clear, the functions that I have excluded from the above list because they are not usually associated with EDD processes (but usually appear in the classical list of functions):

- Plasters the hole with a semi-impermeable filter cake

- Prevents differential sticking
- Carries weighting agents in suspension when circulation is temporarily stopped
- Transmits hydraulic horsepower to the bit face

The top-10 drilling fluid functions in my working list are the most likely to provide the best guidance for the field staff and management of exploration diamond drilling projects. Those are the most important factors by which to determine and measure the success of a diamond drilling fluid.

The working list I have developed wasn't always as clear cut. It has taken a long time to get here for the diamond drilling industry. Way back in the late 1970's a small but significant industry revolution was occurring - a two-pronged battle between wireline drilling versus conventional and impregnated bits versus surface set crowns.

Although both consumable equipment technologies had been developed and trialled sometime earlier, they had become much more closely linked than one might at first have thought. The shift to wireline drilling equipment meant a significantly higher investment, and essentially scrapping the older conventional drill rods. A promise of higher performance and productivity would be the pay-off.

However, in order to achieve that, more reliable, longer lasting and better performing drill bits were required to keep the drill string in the hole and take advantage of the benefits of wireline technique. At the time deeper and harder rocks were being encountered (a cycle that continues today) but the impregnated bit technology was still young and largely untested.

Rapid development of impregnated bit technology (and an investment in research) supported the demand for ever increasing field performance. The race continues today, some 40 years later. It has been learnt that impregnated bits drill faster and further in hard rocks at even higher rotary speeds. Therefore, the demand for more appropriate drilling fluids and support has also developed alongside the equipment battles.

In those heady days when the industry battles raged, the current crop of drilling fluids used in exploration diamond drilling had not yet been conceived. Mostly clean water was the primary choice of drilling fluid – as it may well be today! But the standard options when some benefits of a drilling fluid were required was either a traditional high-solids bentonite-based muds or a low solids option using a biodegradable natural polymer called guar gum.

Both options had significant drawbacks – bentonite systems mainly because of the sheer tonnage of materials required on site, and guar gum because it is highly biodegradable and would "go off" rapidly especially in warmer climes.

I had already initiated an investigation to research into alternatives in my drilling fluids laboratory[ii], when an unexpected opportunity arose. A change in the mining laws instigated a fast track core sampling programme across several staked greenfield coal mining tracts. The drilling was much deeper than expected for exploration of viable coal beds – between about 700 - 1,200 m.

A "forest" of drill rigs appeared overnight across the sites, but the projects very quickly ran into problems. Above the coal beds lay a particularly water sensitive siltstone/mudstone that had been altered by dolerite intrusive dykes and sills. Drillers battled against the conditions with multiple occurrences of stuck rods, fishing jobs and wedged deflections to by-pass lost drill strings. Pretty much a nightmare scenario.

To cut a long story short, a classic case of "opportunity meeting possibility" bore a brand-new inhibitive low-solids exploration diamond drilling fluid – "DrilProp 27."[iii] Revolutionary in itself, and in conjunction with the introduction of wireline drilling techniques and impregnated bits, it was a game changer for the exploration diamond drilling industry.

Drilling Fluid Use

Several reasons come to mind for using a drilling fluid (other than plain water):

- Productivity improvement in the face of many geological challenges
- Reduction of drilling problems and overall drilling cost per metre
- Assistance to drill through difficult geological horizons, otherwise thought impossible
- Improvement of "Down-the-Hole" borehole condition
- Prevention of stuck rods, burnt bits, or other tool losses
- Achievement of drilling project objectives

Drilling Problems

Initially specific exploration diamond drilling fluids were introduced as solutions for sedimentary rocks - especially shales and mudstones rich in swelling clay minerals. Inhibited drilling fluids made it look easy from that point onwards.

Difficult challenges followed - such as thick dolomitic limestone and chert formations, deep hard conglomerates, sandstones and quartzites. Drilling exploration boreholes into the 4,000 - 6,000 m depth range, with multiple branched directional deflections demanded even more from the drilling fluids.

Then solving even more difficult drilling problems such as bit cooling and cleaning, drill string lubrication, vibration, and the ever-present threat of lost circulation – over the years I have had the pleasure to find solutions for the most challenging conditions.

Cut Your Losses!

Lost circulation continues to be the number one reason to suspend the use of drilling fluids. Understandably, it is expensive to simply throw chemicals away by pumping them into the borehole only to flow into the caverns of the earth.

This immediately results in the threat of excessive vibration, high torque and reduced or ineffective bit cooling and cleaning (especially when using plain water). More often than not, lost circulation initiates a cycle of ever declining drilling performance, greater difficulties due to consequential problems, core losses and core quality issues, and caving. Disastrous when it ends in a fishing job due to stuck rods or a burnt-in bit.

All too infrequently is lost circulation stemmed or controlled using lost circulation materials (LCM) of any sort. The physical sizes and clearances of the drill rod, borehole and core barrel sizes essentially preclude the circulation of LCM of any substantial size. When LCM's are pumped in slugs above the loss zone, or through the open hole, they tend to block the borehole, and fail to treat the actual loss zone. A lot of time is wasted, and very poor success rates result.

Borehole Condition

Clearly in order to retain the benefits of using a drilling fluid, and control over the borehole, then two things are needed:

1. A better method to control lost circulation, and
2. A focus on maintaining good borehole condition is key; it must be ingrained within the exploration diamond drilling project managers' and drillers' mindset. The purpose is to enable successful drilling and completion of deep boreholes through any challenging geological structures.

Some drilling fluids can be engineered to resist circulation losses. But the application of drilling fluid chemicals alone will probably never become a single solution. Despite the promise of some new product developments, the twin hazards of lost circulation and caving are often experienced together or one as a result of the other.

Valuable Solution

Collectively the exploration diamond drilling industry has never been keen on, nor has it fully considered or understood the value of borehole cementing. In my experience, the minor use of borehole cementing has been ill conceived and poorly executed.

For instance, I have witnessed contractors pumping 80 tons of cement into a borehole to combat lost circulation – which was then solved by less than 500 litres of an engineered cement slurry applied correctly.

It's not just about cementing a casing in or casing shoe. Nor am I talking about what some people in the industry call grouting – for example, using a dump bailer to drop a few litres of cement grout into position in the hopes of a miracle cure, very seldom achieved.

No! I'm talking about properly engineered cement slurries using tested techniques applied successfully (i.e. with safety and little risk) to properly attack lost circulation, caving and other borehole instability, amongst other purposes. Cementing techniques have been developed as useful tools to resolve numerous other difficult EDD[iv].

As soon as you have within your skillset a means of successfully treating lost circulation - with better than even odds of winning - then it becomes possible to maintain circulation for most of the

borehole drilling effort. Consequently, it becomes economically possible to concentrate on maintaining borehole condition to minimise vibration, substantially lower drill string torque (making more power available for the bit to drill) and prevent caving.

All the benefits of better diamond drilling performance and high-quality core recovery will accumulate to those who are willing to invest in these capabilities. It is likely that significant effort and support at project management level will be essential to achieve this level of operational capability. If you're interested, then please contact me directly to find out how I can help you do just that.

Effective Drilling Fluid Chemicals

In exploration diamond drilling there's too much obfuscation with respect to the description of drilling fluids chemicals. I get it that the products are marketed and sold on a performance basis, but more effort needs to be placed on engineering the field performance.

It's not helpful that suppliers deliberately try to prevent cross correlation of their products with "differentiating" descriptions, and in so doing they prevent users from understanding exactly what they are using and developing capabilities to apply synergistic chemical product combinations.

For the purpose of this paper, let's work with generics, as far as possible, to enlighten everyone.

The simplified product groups to consider are as follows:

- Water treatment / conditioning
- Viscosifiers
- Shale inhibitors
- Surfactants
    - Lubricants
    - Bit coolants and cleaners

Water treatment / conditioning

Most of the drilling fluid products are anionic – or non-ionic. Therefore, they behave poorly in the presence of multi-valent cations, such as calcium (Ca) or magnesium (Mg).

Hard make up water for drilling fluids contain Ca and Mg ions, and drilling fluids can accumulate Ca and Mg as well as other contaminants as a result of dissolution from the rock cuttings or detritus being generated during drilling (e.g. when drilling limestone or dolomite or gypsum rich formations).

The simplest and arguably most effective water treatment additive or drilling fluid conditioning is to treat with ***Sodium Carbonate (Soda Ash***). This will both stabilise the pH in the range 8 - 10 pH and prevent any calcium or magnesium contamination.

Viscosifiers

Three types of viscosifier are useful for exploration diamond drilling:

1. ***High molecular weight PHPA polymer*** – a low cost, rapid yielding, viscous, low solids drilling fluid, exhibiting good lubricity, flexible viscosity, and high degree of shale/clay inhibition - lacks long term stability and needs to be regularly conditioned to replace polymer lost to cuttings coating. PHPA polymers are supplied as liquid (emulsion and suspension types) or as dry polymers (powder and bead types). Liquid polymers are only about 35 – 40% active, with added transport costs, but mix easily with little wastage. Dry polymers are 100% active, but require more effort to mix properly without wastage, and save on transport costs.

2. ***High yielding CMC / high molecular weight PHPA polymer combinations*** – a more stable low solids, polymer drilling fluid with more stable viscosity control, excellent shale inhibition – more costly to make up than the PHPA polymer on its own, offset by better fluid control. CMC type polymers are mainly supplied as 100% active dry powder types – and require good mixing systems to maximise benefits.

3. ***High yield modified (or extended) bentonite clay*** – creating a viscous, non-dispersed, low solids drilling fluid, which can resist lost circulation, and exhibits extreme pressure lubrication of the drill string to reduce torque, provides some "built-in" shale inhibition. Regular bentonite can be used with a bentonite extender (as separate fluid additives) or as a single product mix for easy field use. Always have good high shear mixing facilities to maximise the yield of these viscosifiers.

All three systems may be enhanced with other fluid additives. Most notably liquid lubricants ("soft soap" type or emulsified vegetable oil type), and drilling detergents (see below for more detail).

Viscosity is an important factor for diamond drilling to perform the function of vibration control, especially to limit helical whipping, and other forms of vibration.

Shale inhibitors

Shale and clay inhibition can be provided by the PHPA type polymers (usually applied as a viscosifier too). However, particularly reactive clays and shales require an additional shale inhibitor additive in the drilling fluid system.

Potassium chloride (KCl) is one of the most readily available products – also known as "potash" or "sylvite." Because around 95% of potash is used as a fertiliser, it is generally and widely available.

Potash is highly effective because it dissolves in the water, making the potassium ion (K^+) available for ion exchange with the clays in the shale rocks – replacing other ions such as sodium, magnesium and calcium. At a molecular level, the chemical bonding of the potassium ion in between the clay platelets increases the bond strength and enhances the resistance against water attempting to intrude and soften the clays and shales, and create swelling along the bedding and fracture planes, as well as the borehole wall.

Surfactants

Lubricants

Lubricity is extremely important to reduce equipment wear and smooth the tendency for the drill string to generate other forms of vibration (such as axial or stick-slip twisting vibrations) which can cause rapid wear on drill bits.

Two types of modern lubricants include:

- "Soft soap" type fatty acid based liquid lubricants – mostly linseed oil products
- Emulsified vegetable oil types – e.g. soya bean oils

Excellent references are available[v]. Biobased lubricants are eco-friendlier and are therefore recommended for replacement of petroleum-based lubricants.

Bit coolants and cleaners

Specific groups of surface-active chemicals called surfactants, also exhibit the special purpose and action of a detergent, called detergency: which is to mobilise "dirt" from a surface and prevent its redeposition.

A drilling detergent provides improved wetting and heat transfer from the working bit to the drilling fluid, and effectively clears drilled detritus or cuttings away from the bit and prevents its redeposition in the water ways.

A drilling detergent keeps the drill bit clean and cooled, and therefore can be effective in improving the useful life of the drill bit. The most effective drilling detergents are either anionic or non-ionic in chemical nature, which means that they will usually work well with other drilling fluid additives, work well in an alkaline fluid of about 8 – 10 pH, and can tolerate salts in solution (such as potassium chloride or calcium and magnesium salts due to water hardness).

Some detergents are high foaming, and therefore care should be taken not to aerate the drilling fluid, or if necessary, to use an effective defoamer/antifoam additive to control troublesome foams.

Drilling Fluid Chemical Availability

Chemical suppliers usually establish themselves in any area where there is significant drilling taking place.

If exploration diamond drilling projects are near oil & gas exploration areas, then major chemical suppliers may already be present[vi].

In many major industrial centres around the world, there are also chemical manufacturers or their agents supplying which drilling contractors may well take advantage of by buying directly[vii]. It is well within the scope of any contractor to put together the small range of drilling fluid chemicals that can be used advantageously on their own projects. Additional support and guidance is available by contacting this author.

Over the years though a few chemical suppliers have developed specialised businesses in supplying the diamond drilling industry[viii].

For interest and possibly to help any reader (Note: use at your own risk) I have selected a few of the abovementioned chemical suppliers and prepared a comparison chart to demonstrate a loose equivalence of their products for exploration diamond drilling – see appendix A.

Powerful tool

My position is this: drilling fluid chemicals can be (and often are) easily over-rated, and misunderstood (especially because of the marketing-based promotional descriptions). There are just a few straight-forward functions that are important and have proven to provide benefits to the exploration diamond driller.

Applied sensibly, using drilling fluid chemical additives are a powerful tool that will generate a handsome return on investment in terms of providing preventative and corrective benefits in maintaining an open borehole to work in.

However, always follow the golden rules:

1. Maintain circulation by successfully ***treating any circulation loss zones promptly***.
2. Use the drilling fluid to ***maintain good borehole condition*** to reduce torque, dampen vibrations, keep the bit cool and clean, and enable the driller to operate the rig efficiently to drill faster and core most effectively.

APPENDIX A:

Exploration Diamond Drilling Fluid Chemicals Chart

Note: the products mentioned below are neither promoted nor endorsed by this author and may or may not be precisely equivalent or comparative, nor may this chart be entirely accurate. Use at your own risk.

Generic Type of Additive	Matex	AMC	Baroid IDP	BASF	General Chemical Suppliers
WATER TREATMENT / CONDITIONING					
Soda Ash	Soda Ash	Soda Ash	Soda Ash		Soda Ash
Anti-foam / Defoamer			Bara-Defoam 500		Defoamer Anti-foam TBP#
VISCOSIFIERS					
PHPA* powder / bead	DD-2000		Quick Mud Gold Barad-399 Core	Alcomer 120	Alcomer 120 PHPA
Liquid PHPA	DD-955 / UltraVis	Ezee Mix / Liquid Pol	EZ Mud plus	Alcomer 120L	Alcomer 120L Liquid PHPA
Low viscosity PHPA powder		CR-650	EZ Mud Gold	Alcomer 507 Polydrill	Alcomer 507
Dry suspended PHPA	DD-Express / Sand Drill		Quik Mud D50		
CMC high viscosity		Ezee-PAC R	PAC-R		
Bentonite		Aus Gel Aus Gel Xtra	Quik-Gel Quik-Gel Gold		Bentonite
Extended Bentonite			Quik-Bore		
Bentonite extender polymer				Alcomer 180 Alcomer 1771	Alcomer 180 Alcomer 1771
SHALE INHIBITORS					
PHPA*	DD-955		EZ-Mud DP EX-Mud Gold	Alcomer 120L Alcomer 110	Alcomer 120L Alcomer 110
Potassium Chloride (KCl) (fertilizer grade)					Potassium Chloride
SURFACTANTS – LUBRICANTS (lubrication)					
Emulsified vegetable oils (usually soyabean oil based)	Torqueless		Vibra Lube Baro Lube Gold Seal DD-8		
"Soft soap" lubricants (usually linseed oil-based)			Core Lube (linseed oil based)		Soft Soap (linseed oil or other vegetable oil-based products)
SURFACTANTS – DETERGENTS (bit cooling and cleaning)					
Drilling detergent – anionic (often SLES = Sodium Lauryl ether sulphate based)		Aus-Det Xtra	Con Det DD-8		Teepol
Drilling detergent – nonionic (usually alkylbenzene sulphonates)		AMC-Det	Penetrol		

Matex drilling fluids – a Canadian based manufacturer with distribution partners worldwide
AMC – an Imdex company with world-wide presence in mining locations
Baroid IDP – a Halliburton company with worldwide presence (mainly associated with O&G industry)
BASF – multinational chemical manufacturer with worldwide distribution to industry
General chemical suppliers – distributors of chemical products for industry and mining

Note: Other manufacturers and suppliers are available.
Many of the above products are available via distributors in mining and exploration active territories.

* PHPA = partially hydrolysed Polyacrylate / polyacrylamide
# TBP = Tributyl Phosphate

End Notes & References

[i] Drilling, Completion & Workover Fluids 2015, supplement to World Oil magazine, published by Gulf Publishing Company.

[ii] A fully equipped drilling fluids laboratory and drilling services centre in Cape Town, South Africa – from where DrilChem (Pty) Ltd provided mud engineers and Oceaneering diving services to SOEKOR, the South African state operated O&G exploration company.

[iii] "Dril-Prop 27" was a solution I developed during my work as technical director at DrilChem (Pty) Ltd – many more drilling fluid solutions followed at the time that the exploration diamond drilling market was undergoing major change.

[iv] Refer to my papers on Cementing Exploration Boreholes for more on how these skills and techniques have developed. Also see my paper on Chemical Grouting for more on how and where simple and controlled chemical grouts can work wonders for the exploration diamond driller.

[v] "Surfactants in Tribology" edited by Girma Biresaw and K.L. Mittal – especially chapters 15 and 17. Other references include "Surfactants Europe" edited by Gordon L Hollis, and an article in European Lubricants Industry Magazine Issue 140 August 2017 entitled "Biobased Lubricants"

[vi] Oilfield chemical service companies such as MI-Swaco (a Schlumberger group company), Baroid (a Halliburton group company), CETCO, Di-CORP, Baker-Hughes and many more.

[vii] BASF is a global chemicals manufacturer, which offers several excellent products that can be used for exploration diamond drilling.

[viii] AMC (an Imdex group company), Matex Control Chemicals, SinoMud, Baroid IDP (the industrial drilling products division of this Halliburton group company). A number of these specialise in diamond drilling fluids and have distribution supplier relationships with major drilling equipment suppliers servicing active mining and mineral exploration areas.