Fundamentals of Onshore Drilling

Fundamentals of Drilling Principles of Drilling Fluid Technology presentation No. 5

references:

Drilling Mud – Why do We Deal With?

- Bottomhole Cleaning
- Cuttings Transport
- Borehole Wall Support
- Balancing Formation Pressure
- Cooling the Bit
- Hydraulic Power Transmission
- Data Transmission (MWD)
- Reducing Friction
- Corrosion Protection

Engineers → Mud → Information Carrier → Scientists

Mud/Fluids → Gas → Tracers → Cuttings → Mud → Gas → Fluids → Cuttings → Cores

Aiding Scientific Evaluation

Borehole Logging
Technical Key Functions of Drilling Fluids

Mud Circulation System

Transport of Cuttings to Surface
Support of Borehole Wall
Transmission of Data/Hydraulic Power
Cooling Bit
Balancing Formation Pressure
Cleaning the Bottom of the Hole

Hydraulic Optimization
Pump Pressure = f(Pump Rate, Mud Viscosity)

Protection against Corrosion
Aiding Solids Removal
Reducing Friction Torque/Drag
Mud Properties Controlling Technical Key Functions

**Functions**
- Cleaning the Bottom of the Hole
- Transport of Cuttings to Surface
- Hydraulic Power
- Data Transmission
- Cooling the Bit
- Borehole Wall Support/Stabilization
- Balancing Formation Pressure
- Reducing Friction/Torque and Drag
- Protection against Corrosion
- Aiding Cuttings Removal and Solids Control

**Properties**
- Rheological Parameters
  - Viscosity
  - Thixotropy
- Density
- Filtration Parameters
- Free Water Capacity
- Lubricity Coefficient
- Chemical Composition
  - pH
  - Physico-chemical Parameters
- Solids Content
  - Weighted/Unweighted

**Complex Interaction**
Fundamentals of Cutting Transport

Transporting of Cuttings to Surface

\[ V_{\text{ann}} \]: Mud Velocity in Annulus
depends on:
- Pump rate,
- Annular Geometry

\[ V_{\text{sett}} \]: Cutting Settling Velocity
depends on:
- Mud Parameters
  - Rheology (Viscosity)
  - Density
- Cutting Parameters
  - Density
  - Diameter
  - Shape

\[ V_{\text{ann}} \gg V_{\text{sett}} \]

Basic Law of Cuttings Transport
\[
\left( \frac{V_{\text{ann}} - V_{\text{sett}}}{V_{\text{ann}}} \right) > 50\%
\]
Fundamentals of Cutting Transport

Drilling/Mud Circulation

Roundtrip/Circulation Break

Holding Cuttings in Suspension

$\tau_0$: Yield Strength of Mud depends on:
- Rheological Behaviour
- Gel Strength, Thixotropy

$\tau_{cutt}$: Tangential/Normal Stress due to Cutting Weight depends on:
- Cutting Diameter ($d_c$)
- Cutting Density ($\rho_c$)
- Cutting Shape
- Mud Density ($\rho_m$)

$\tau_{cutt} = \left( d_c \times g (\rho_c - \rho_m) \right) / 6$

$\tau_{cutt} < \tau_0$
Cutting Transport – The Role of Drilling Fluid Rheology

Circulation/Drilling
Dynamic Carrying Capacity

- Rheological Behaviour while Flowing
- Viscosity dependent on Shear Rate

Circulation Break/Roundtrip
Static Carrying Capacity

- Rheological Behaviour while Stationary
- Thixotropy: Fluid $\leftrightarrow$ Gel reversible
Cutting Transport – The Role of Drilling Fluid Rheology
Drilling Mud Viscosity – Measuring Equipment

Rotational Viscosimeter

Determination of Shear Dependent Viscosity by Measuring Flow Curve at different Rotational Speeds

Marsh Funnel

Measuring Outflow time (s)
Water: 26 s

946 cm$^3$
Drilling Mud Viscosity – Measuring Equipment
Flow Models Describing Pseudoplastic Drilling Fluid Rheology

**Shear Stress – Shear Rate Diagram**

- **True Viscosimeter Readings**

  **Bingham Fluid**
  
  \[
  \text{YP: Yield Point} = 2 \times R_{300} - R_{600}
  \]
  
  \[
  \text{PV: Plastic Viscosity} = R_{600} - R_{300}
  \]
  
  \[
  \tau = \text{YP} + \text{PV} \times \gamma
  \]

- **Power Law Fluid**
  
  \[
  \text{K: Consistency Index} = \frac{R_{300}}{511} \times n
  \]
  
  \[
  \text{n: Power Law Coefficient} = \log\left(\frac{R_{600}}{R_{300}}\right) / 0.301
  \]
  
  \[
  \tau = \text{K} \times \gamma^n
  \]
Shear Thinning of Drilling Fluids – Influence on Drilling Process

- Low Shear-Range
  - High Viscosity
- High Shear-Range
  - Low Viscosity

\[ \mu_{\text{app}} = \frac{\tau}{\gamma} \]

- Newtonian Fluid
- Bingham Fluid
- Power Law Fluid

Annulus -> Cuttings Transport

Bingham Asymptotic Line for high Shear Rates \( \mu_{\text{app}} \rightarrow PV \)

- Drillpipe -> Pressure Loss
- Bit Nozzles -> Hydraulic Power at Bit
- Solids Control -> Cutting Removal

\[ \mu_{\text{app}} = \mu = \text{const} \]
Influence of Yield Point on Cuttings Transport Efficiency

Annular Geometry: 5” Drillpipe/12 ¾” Hole

Transport Ratio (%)

Pump Rate (l/min)
- 1000
- 1500
- 2000

Minimum Value (50%)

Cutting Density: 2,9 kg/dm³
Cutting Diameter: 15 mm
Mud Density: 1,25 kg/dm³
Plastic Viscosity: 30 mPas

Yield Point YP (lbs/100sqft)
Gel Building Properties of Drilling Fluids

Time dependent Gel Strength

- Drilling Fluids show thixotropic properties
- Thixotropy: GS@10min-GS@10s
- Measured with Rotational Viscosimeter @ 3 RPM

Gel Strength GS (Pa)

- Initial GS after 10s
- GS too high → high Surge/Swab Pressures
- GS too low → Insufficient Static Carrying Capacity for Cuttings

Progressive Gel
- fragile Gel
desirable

gel dangerous

Pump Pressure necessary for Breaking Gel

- Mining Drilling
  5 1/2"DP/6" Hole
  Narrow Annulus
- KTB Pilot Hole

- Rotary Drilling
  5 1/2"DP/12 1/4" Hole
  5 1/2"DP/17 1/2" Hole

- Excessive Pump Pressures
- Formation Fracturing/Lost Circulation
- Borehole Instability
- Uncontrolled Influx of Formation Fluids
Optimizing Drilling Hydraulics

Objective: Maximizing Hydraulic Power at Bit

Rule of Thumb for Rotary Drilling: 2/3 of total Pressure Loss at Bit

Jet Nozzles in a Roller Cone Bit

Minimizing Parasitic Pressure Losses
PV as low as possible,
YP as high as necessary for Cuttings Transport

Hydraulic Power HP

Surface
Parasitic Pressure Loss
Bit
Optimum

Pump Rate
Impact Parameters on Parasitic PL
- Annular Geometry
- Surface Equipment
- Drillpipe Size
- Mud Rheology (YP and PV)
Mud Additives Controlling Rheology

**Viscosifiers**
- Clays
  - Bentonite
  - Attapulgite
  - Sepiolite
  - Hectorite
- Polymers
  - Biopolymers
    - Xanthan
    - Guar Gum
  - Polyacrylate/Polyacrylamides
  - HEC (Hydroxyethylcellulose)
  - CMC (Carboxymethylcellulose)

**Dispersants/Deflocculants**
- Lignosulfonates
- Lignites
- Phosphates
- SSMA (Styrene Sulfonate Maleic Anhydride)
  (important for High Temperature Applications)
State Diagram of Colloidal Montmorillonite Suspension in Water

- Aggregation: decreasing plastic viscosity (PV), increasing filtration rate, reduced water bonding
- Dispersion: increasing plastic viscosity (PV), increasing water bonding

Clay Platelets
- dispersed
- reversible
- aggregated
- irreversible

Face to Face
- aggregated and flocculated

Increasing Yield Point (YP) and Gel Strength
- Flocculation
Support of the Borehole Wall – Balancing Formation Pressure

While Drilling Open Hole
Mud Column should act as „Hydraulic Casing“

- Sufficient Mud Density
- Good Filtration Properties

Insufficient Mud Density
Bad Filtration Properties

- Uncontrolled Fluid Entry
- Borehole Instabilities
- Differential Sticking
Balancing Formation Pressures

Normal Drilling (overbalanced)
Mud Pressure > Formation Pressure

Pressure of Mud Column
\[ P_{\text{mud}} = \text{Density}_{\text{mud}} \times g \times \text{Depth} \]

Formation Pressure Profile

- Petrostatic
- Sub hydrostatic
- Geopressed Aquifer
- Hydrostatic
- Frac Gradient
Instruments for Measuring Mud Density

Hydrometer

Mud Balance
Instruments for Measuring Mud Density
Weighting Materials for Drilling Muds

- **Inert Solids**
  - Calcium Carbonate
  - Barite
  - Ilmenite
  - Iron Powder
  - Lead Oxide

- **Solids Free Salt Solutions**
  - KCl
  - NaCl
  - Sodium Formate
  - CaCl₂
  - NaBr
  - K₂CO₃
  - Potassium Formate
  - CaBr₂
  - ZnBr₂
Solids Content and Mud Density for Various Weighting Materials

- Calcium Carbonate (2.7 kg/dm³)
- Barite (4.2 kg/dm³)
- Ilmenite (4.8 kg/dm³)
- Iron Powder (7.9 kg/dm³)
- Lead Oxide (9.1 kg/dm³)

Tolerable Solids Content
Supporting the Borehole Wall – Hydraulic Casing Effect

Mud Properties
- Mud Density -> Pressure Support
- Filtration Characteristics -> Wall Sealing
- Free Water Activity -> Interaction Rock

Beginning Filtration  Buildup of Filtercake

Filter Cake

Permeable Formation
Pore Pressure

Invasion of:
Mud Filtrate

Mud Particles

Wall sealed

Good Filtration Characteristics
- Quick Filtercake Buildup
- Low Filtration Rate
- Filtercake
  - thin
  - impermeable
  - slick

Minimizing Formation Damage
Filtercakes and Differential Sticking Mechanism

Graph showing Overpull required to unstick BHA as a function of Pore pressure (SG) with different thicknesses of mudcake (4 mm, 7 mm, 1 mm). The graph indicates the maximum OVPL required to unstick the BHA, with a peak of 130 tons.

Diagram illustrating the concept of differential sticking with filtercake thickness affecting the sticking force. The diagram shows the sticking area and force for both thin and thick mudcake conditions.
Destabilisation of Red Shale Caused by Contact with Water

Original Sample
CST > 3600 s

Sample after 20 min in Water
CST < 70 s

Sample after 24h in Dehydril HT (2%)

Destabilisation Process is favoured by High Free Water Activity

High Free Water Activity <-> Low CST
Low Free Water Activity <-> High CST
Additives Controlling Filtration Properties and Free Water Activity

Bentonite ← Polymers

Polymers act as Protection Colloids Preventing Aggregation of Clay Particles

- Starch
- Polyanionic Cellulose (PAC)
- Sodium Carboxymethylcellulose (CMC)
- Hydroxyethylcellulose (HEC)
- Polymers/Polyacrylamides
- Vinylsulfonate/Vinylamide-Copolymers (VS/VA)

Protection Polymer Cover

Protein by Na⁺-CMC-Polymer

protected Bentonite in Salt water
Prevention of Lost Circulation – Factors to Consider

Types of Lost Circulation Zones

- High Permeable Gravel
- Natural/Artificial Fractures
- Cavernous Formation

Preventive Methods

- Reducing Mud Density
- Avoiding Pressure Surges
- Lowering Gel Strength
- Lowering Equivalent Circulation Density (ECD)

Fighting Against Lost Circulation

Application of Sealing Material

- Sealing at Fracture Face
- Sealing within the Fracture

Proper Size Distribution

Types of Materials used:

- Fibrous (Raw Cotton, Mineral Fibers, Glass Fibers)
- Flaky (Cellophane, Mica, Cotton Seed Hulls)
- Granular (Perlite, Ground Plastic, Nut Shells, Wood)
- Thick Slurry Pills (Bentonite/Polymer, Cement)
Reducing Friction – Controlling Torque / Drag

- Normal Force $F_N$
- Friction Force $F_R$

$F_R = \mu \cdot F_N$

- Borehole Curvature
- Dogleg Severity: deg/m
- Rotating Drillstring
- Trip In/Out Drillstring
- Narrow Annulus
- Mining Drilling

- Drag (Trip In/Out)
- Torque (Rotation)

- Mud Lubricity Coefficient
Lubricity Coefficients of Drilling Muds

- Air
- Water
- Water with Mixture of Triglycerides
- Biopolymer Solution
- Bentonite Mud
- Bentonite Mud with Graphite
- Bentonite Mud with Triglycerides
- Synthetic Hectorite
- Diesel Oil
- Oilbase Mud
Inhibiting Corrosion

Corrosion is the Major Cause of Drillpipe Failures

**Forms of Corrosion**
- Uniform Corrosion
- **Localized Corrosion (Pitting)**
  - Bimetallic Corrosion
  - Oxygen Concentration Cells
    - Crevice Corrosion
    - Air/Water Interface
    - Oxygen Tubercles
    - Scaling/Sludges
- Corrosion Fatigue
- **Stress Corrosion**
  - Sulfide Cracking
  - Hydrogen Embrittlement

**Measures**
- Raising pH of Mud
- Reducing dissolved Oxygen in Mud
  - Vacuum Degassing
  - Oxygen Scavengers
    - Sodium Sulfite
    - Sodium Nitrite
- Addition of Corrosion Inhibitors
  - Filming Amines
  - Sulfide Scavengers
  - Zinc Carbonate
  - Sodium Molybdate
Mud Circulation System and Solids Control Equipment

Mud Properties Must Aid Effective Cuttings Removal

Solids Control Equipment Is the Base for Cutting Sampling

Mud Pump

Standpipe

Kelly Hose

Swivel

Kelly

Rotary Table

Desilter

Desander

Degasser

Mud Return Flowline

Suction Pit

Shaker Screen

Drillpipe

Borehole

Drill collar

Bit
Mud Circulation System and Solids Control Equipment
Solids Removal by Hydrocyclones

Desilter
- 12-20 Hydrocyclones Battery
- Diameter: 2 – 6 inch
- Cutting Size: 15 – 40 μ

Desander
- 2-3 Hydrocyclones Battery
- Diameter: 6 – 12 inch
- Cutting Size: 40 – 74 μ
Solids Removal by Decanting Centrifuges

Application Areas and Operating Parameters

**Removal of Ultrafine Solids**
- Particle Size: > 5 μ
- RPM: 2500 – 3300
- G-Force: 1200 – 2100

**Barite Recovery in Weighted Muds**
- Particle Size: > 4 – 7 μ
- RPM: 1600 – 1800
- G-Force: 700 – 800
Classification of Mud Systems

- Air/Foam
  - Air
  - Foam
- Water Base
- Oil Base
  - O/W
  - W/O Invert
- Solids Free
  - synth. Hectorite
- Solids Based
  - Bentonite/Polymer unweighted
  - Bentonite/Polymer weighted
<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>▪ Low Cost</td>
<td>▪ Poor Cuttings Transport Efficiency</td>
</tr>
<tr>
<td>▪ Good Penetration Rates</td>
<td>▪ No Static Carrying Capacity</td>
</tr>
<tr>
<td>▪ Good Solids Removal</td>
<td>- Cuttings</td>
</tr>
<tr>
<td>▪ Excellent Conditions for Geoscientific Investigations</td>
<td>- Weighting Material (Barite)</td>
</tr>
<tr>
<td>- Cuttings Analysis</td>
<td>▪ Poor Lubricity Coefficient</td>
</tr>
<tr>
<td>- Geochemical Mass Balance</td>
<td>▪ Uncontrolled Filtration</td>
</tr>
<tr>
<td>- Detection of Formation Fluids And Gases</td>
<td>▪ Poor Borehole Wall Support</td>
</tr>
<tr>
<td>- Borehole Logging</td>
<td>▪ Destabilisation of Formation Rocks</td>
</tr>
<tr>
<td>- Hydraulic Testing</td>
<td></td>
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</tbody>
</table>
Characterization of Mud Systems – Bentonite/Polymer Muds

Bentonite/Polymer Muds are Complex Colloidal Systems

Advantages

- Control of Properties
- Good Cuttings Transport Efficiency
- Good Static Carrying Capacity
- Good Solids Removal
  - Cuttings
  - Weighting Material
- Good Filtration Properties
- Good Borehole Wall Support

Disadvantages

- Complex System
- High Solids Content
- Organic Additives
- Impairment of Geoscientific Investigations
  - Cuttings Analysis
  - Geochemical Mass Balance
  - Detection of Formation Fluids and Gases
  - Borehole Logging
  - Hydraulic Testing
## Typical Composition of Bentonite / Polymer Muds

<table>
<thead>
<tr>
<th>Components</th>
<th>Concentration (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay</td>
<td></td>
</tr>
<tr>
<td>- Bentonite</td>
<td>60 – 70</td>
</tr>
<tr>
<td>- Attapulgite</td>
<td></td>
</tr>
<tr>
<td>- Sepiolite</td>
<td></td>
</tr>
<tr>
<td>Polymer (Protective Colloid)</td>
<td></td>
</tr>
<tr>
<td>- CMC</td>
<td>10 - 20</td>
</tr>
<tr>
<td>- PAC</td>
<td></td>
</tr>
<tr>
<td>- Starch</td>
<td></td>
</tr>
<tr>
<td>- PAA</td>
<td></td>
</tr>
<tr>
<td>- VS/VA</td>
<td></td>
</tr>
<tr>
<td>Deflocculant/Dispersant</td>
<td></td>
</tr>
<tr>
<td>- Lignosulfonate</td>
<td>3 - 6</td>
</tr>
<tr>
<td>- SSMA Polymer</td>
<td></td>
</tr>
<tr>
<td>Sodium Hydroxide/Carbonate</td>
<td></td>
</tr>
<tr>
<td>pH: 9 - 10</td>
<td></td>
</tr>
<tr>
<td>Barite</td>
<td></td>
</tr>
<tr>
<td>Density: 1200 - 1600</td>
<td></td>
</tr>
</tbody>
</table>
Characterisation of Mud Systems – Biopolymer Mud

Chemical Structure
Of Xanthane (XC)

Biopolymer Muds are Solutions of High Molecular Biopolymers in Water

Advantages
- Solids Free
- Good Cuttings Transport Efficiency
- Excellent Shear Thinning
- Sufficient Static Carrying Capacity
- Good Lubricity Coefficient
- Efficient Solids Removal

Disadvantages
- Limited Temperature Stability (120°C)
- Bacterial Degradation
- Impairment of Geoscientific Evaluation
  - Gas Analysis (artificial Methane Due to Polymer Degradation)
- No Filtration Control
Characterisation of Mud Systems – Oil Base Muds

Oil Base Muds are Emulsion Systems

Advantages
- Excellent Lubrication
- Favourable to Borehole Stability
- No Corrosion
- Good Temperature Stability
- Deviated Wells/Extended Reach Well

Disadvantages
- Complex System
- Impairment of Geoscientific Investigations
  - Borehole Logging (No Electrical Conductivity)
  - Detection of Formation Fluids and Gases
- High Cost
- Environmental Problems
THE END!!!

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