International Association of Drilling Contractors

IADC UNDERBALANCED DRILLING COMMITTEE

"Fluid Selection for Underbalanced Drilling Operations"

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by the
Fluids Subcommittee

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Initial fluid selection for underbalanced drilling operations is classified into five major fluid types based primarily equivalent circulating density (gas, mist, foam, gasified liquid, liquid). Further delineation within these groups is dependent upon considerations outlined in the IADC-UBO Classification System for Underbalanced Wells (Level 0,1,2,3,4,5) that further delineates selection based on well flow characteristics, well fluid type, surface operating pressure, fluid containment, well control, and applicable health, safety, and environmental issues.

Final fluid selection for underbalanced drilling operations can be extremely complex. Key issues such as reservoir characteristics, geophysical characteristics, well fluid characteristics, well geometry, compatibility, hole cleaning, temperature stability, corrosion, drilling BHA, data transmission, surface fluid handling and separation, formation lithology, health and safety, environmental impact, fluid source availability, as well as the primary objective for drilling underbalanced all have to be taken into consideration before final fluid design.

The objective of this paper is to develop guidelines for optimum selection of a drilling fluid for underbalanced drilling operations that meets all health, safety, and environmental requirements.

IADC UNDERBALANCED DRILLING COMMITTEE
Fluids Subcommittee
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"Fluid Selection for Underbalanced Drilling Operations"

INTRODUCTION

A very important part in the design of an underbalanced drilling operation is the selection of the drilling fluid.

Drilling fluid selection will effect equivalent circulating density (ECD), borehole stability, formation damage, under balance pressure, surface equipment configuration, and waste management considerations. Given these and other important operational and economical considerations, a Selection Fluid Guide for Underbalanced Drilling Operations has been developed. This Selection Guide is presented in three main "stages" for planning, based primarily on information and/or calculations needed for evaluation, and on the most likely options resulting from the evaluation. The stages are further divided into "blocks" so that the evaluation and selection processes can be conducted in a logical and organized manner.

The three main stages of the Selection Guide are:

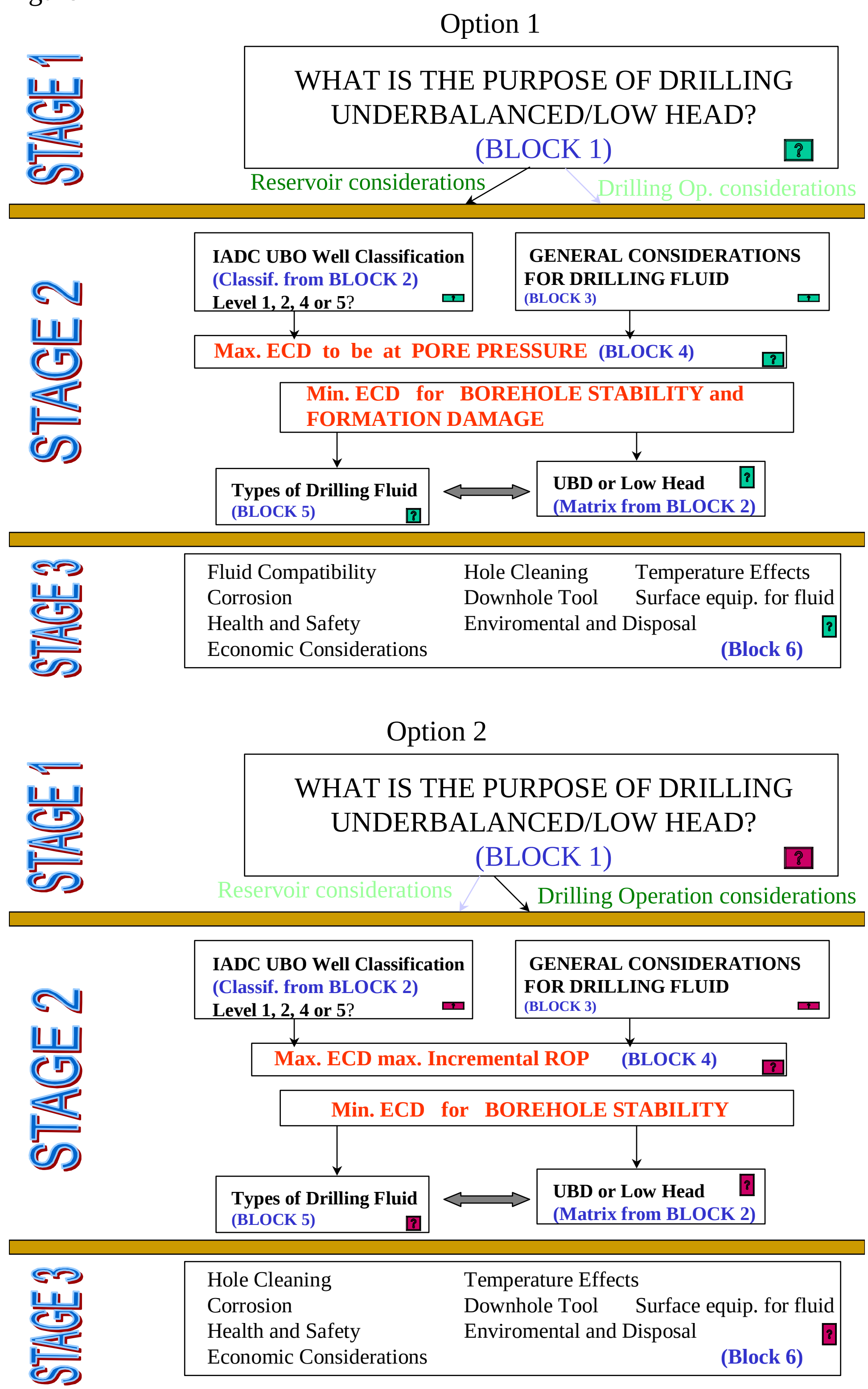
- **STAGE 1**: ***What are The Objectives?***
  Is the purpose for drilling underbalanced related to: (a) Reservoir Considerations, or (b) Drilling Operation Considerations?
  General Considerations must be evaluated to determine the purpose for drilling under balanced. These include mainly skin damage/ productivity index (reservoir) and borehole stability/rate of penetration (drilling). (BLOCK 1)

- **STAGE 2**: ***What types of fluids can be considered, near or underbalanced?***
  Data must be collected, calculations made, and results evaluated in order to determine the level of under balance pressure.
  What is the well classification? (BLOCK 2)
  What are the general considerations? (BLOCK 3)
  What is the ECD? (BLOCK 4)
  What classifications of fluids should be considered? (BLOCK 5)

- **STAGE 3**: ***What is the optimum drilling fluid selection?***
  Final fluid selection must be based on fluids compatibility, borehole cleaning and stability, temperature, corrosion effects, and environmental issues. Primary well design considerations must be reviewed before making a final fluid selection. (BLOCK 6)

A view of the Selection Fluid Guide decision tree, including stages and blocks, can be seen in Figure 1. More detailed explanations of the decision elements will be given in the following parts of this paper.

Figure 1


Option 1
STAGE 1
WHAT IS THE PURPOSE OF DRILLING UNDERBALANCED/LOW HEAD?
(BLOCK 1)
?
Reservoir considerations
Drilling Op. considerations
STAGE 2
IADC UBO Well Classification
(Classif. from BLOCK 2)
Level 1, 2, 4 or 5?
GENERAL CONSIDERATIONS FOR DRILLING FLUID
(BLOCK 3)
Max. ECD to be at PORE PRESSURE (BLOCK 4)
?
Min. ECD for BOREHOLE STABILITY and FORMATION DAMAGE
Types of Drilling Fluid
(BLOCK 5)
?
UBD or Low Head
(Matrix from BLOCK 2)
?
STAGE 3
Fluid Compatibility
Corrosion
Health and Safety
Economic Considerations
Hole Cleaning
Downhole Tool
Enviromental and Disposal
Temperature Effects
Surface equip. for fluid
?
(Block 6)
Option 2
STAGE 1
WHAT IS THE PURPOSE OF DRILLING UNDERBALANCED/LOW HEAD?
(BLOCK 1)
?
Reservoir considerations
Drilling Operation considerations
STAGE 2
IADC UBO Well Classification
(Classif. from BLOCK 2)
Level 1, 2, 4 or 5?
GENERAL CONSIDERATIONS FOR DRILLING FLUID
(BLOCK 3)
Max. ECD max. Incremental ROP (BLOCK 4)
?
Min. ECD for BOREHOLE STABILITY
Types of Drilling Fluid
(BLOCK 5)
?
UBD or Low Head
(Matrix from BLOCK 2)
?
STAGE 3
Hole Cleaning
Corrosion
Health and Safety
Economic Considerations
Temperature Effects
Downhole Tool
Enviromental and Disposal
Surface equip. for fluid
?
(Block 6)

STAGE 1: ***WHAT ARE THE OBJECTIVES OF DRILLING UNDERBALNCED ?*** (Block 1)

A very important decision to be made in the planning stage of fluid selection is the determination of the primary objective for drilling under balanced. Is it reservoir considerations or drilling operations performance?

Block 1
What is the Purpose for Drilling Underbalanced?

Reservoir considerations:

- Reduction of Skin damage in the target production zone
- Increase productivity index
- Increase recoverable reserves
- Increase production rate
- Produce reservoir fluids for sale while drilling

Drilling Operation considerations

- Ability to drill through transition zones
- Increased Rate of Penetration (ROP)
- Reduction of lost circulation incidents
- Reduction of drilling downtime

KEY ISSUES FOR DRILLING FLUID SELECTION BASED ON RESERVOIR CONSIDERATIONS

- What is the lowest and the highest **pore pressure** and depth of the target production zone.
- What is type of **formation** and **formation damage** mechanism?
- Reservoir **characteristics of the production zone (Block 3)**.
- Bore hole stability (**geophysics/geomechanical)?**
- What is potential **type** and anticipated **rate** of production?

KEY ISSUES FOR DRILLING FLUID SELECTION BASED ON DRILLING OPERATION CONSIDERATIONS

- Compare analysis of drilling fluid/gas and formation/cuttings that will be brought to surface
- Review drilling fluid handling and solids processing equipment
- Review Nitrogen/water/formation oil/formation gas/foam handling and separation equipment requirements
- Review emulsion handling/separation/issues and requirements
- Review pressure control equipment specifications and effect on fluid handling and separation requirements
- Review erosion effects on surface equipment
- Review of returned fluids on elastomers
- Review hydrocarbon separation, storage and transmission requirements.

STAGE 2: *WHAT TYPES OF FLUIDS CAN BE CONSIDERED?* (Blocks 2, 3, 4, & 5)

Block 2
What is the IADC UBO Well Classification? (UBO = Under Balanced Drilling Operations)

Level 0 – Performance enhancement only, no hydrocarbon containing zones.

Level 1 – Well incapable of natural flow to the surface. Well is "inherently stable" and is a low level of risk from a well control point of view.

Level 2 -- Well capable of natural flow to surface but enabling conventional well kill methods and limited consequences in case of catastrophic equipment failure.

Level 3 – Geothermal and non-hydrocarbon production. Maximum shut-pressure is less than UBO equipment operating pressure rating. Catastrophic failure has immediate serious consequences.

Level 4 – Hydrocarbon production. Maximum shut-in pressure is less than UBO equipment operating pressure rating. Catastrophic failure has immediate serious consequences.

Level 5 – Maximum projected surface pressures exceed UBO operating pressure rating but are below BOP stack rating. Catastrophic failure has immediate serious consequences.

Block 3
Have the General Considerations for Selecting a Fluid been reviewed?

Reservoir	Formation type (sand, limestone, clays, …)
	Pore pressure
	Temperature
	Formation bearing fluids (water, oil, gas) and characteristics (composition water, gas, PVT(pressure, volume ,temperature analysis..)
	Geophysical / Geomechanics information
	Permeability
	Porosity
Well Geometry	Directional characteristics
	Hole size
	Proposed casing program
Offset HistoryLogs	Mud logs
	Production history
	Well test data
	Seismic
	Drilling reports

Block 4

Equivalent Circulating Density (“ECD”)

What is the maximum ECD for Pore Pressure?

What is the minimum ECD for Borehole Stability?

1. **Bottom hole pressure**
    - ♦ Fluid modeling
    - ♦ Drawdown pressure vs production rate
    - ♦ Pressure transient testing and analysis
2. **Geomechanical considerations**
    - ♦ Empirical models
    - ♦ Lab test for cores
    - ♦ Log data (sonic)
3. **Reservoir fluid type**
    - ♦ Effect of reservoir inflow on Equivalent Circulating Density (ECD)
4. **PVT curves**

Block 5

IADC UBO Fluids Classifications

(ppg = pounds per gallon)

Classification	Fluid	ECD
GAS	Air	0.01-0.1 ppg
	Nitrogen	0.01-0.1 ppg
	Natural gas	0.01-0.1 ppg
MIST	Mist	0.1 – 0.3 ppg
FOAM	Dry	0.3 – 3.5 ppg
	Wet	3.5 – 6.9 ppg
GASSIFIED LIQ		4.0 – 6.9 ppg
LIQUID	Oil based	7.5 –19.0 ppg
	Emulsion	7.5 –17.0 ppg
	Water based	8.3 –19.0 ppg

Block 5, continued.
Additional Information

IADC UNDERBALANCED OPERATION COMMITTEE
Fluids Subcommittee – Equipment Requirements

Fluid Group	Fluid	Equipment Requirements
Gas Drilling	Air	Compressors, boosters, mist/foamer pump, blooie line, rotating head/diverter, flare/flame, drill string floats
	Nitrogen	Cryogen tanks & heaters – OR – membrane nitrogen generators, boosters, mist/foamer pump, blooie line, rotating head/diverter, flare/flame, drill string floats
	Natural Gas	Pipeline / gas source, compressors, boosters, mist/foamer pump, blooie line, rotating head/diverter, flare/flame, drill string floats
Mist Drilling	Mist	Source of gas, small injection pump, compressors, boosters, mist/foamer pump, blooie line, rotating head/diverter, flare/flame, drill string floats
Foam Drilling	Dry Foam	Source of gas, compressors, boosters, foam generator, blooie line, rotating head/diverter, flare/flame, special metering equipment, defoaming tank and pump, drill string floats
Gasified Liquid Drilling	Gasified Liquid	Gas/liquid separator, compressors, boosters, flare line, rotating head/diverter, flare/flame, drill string floats
Liquid Drilling	Oil Based	Rotating head/diverter, drill string floats, cuttings disposal
	Emulsion	Rotating head/diverter, drill string floats, cuttings disposal
	Water Based	Rotating head/diverter, drill string floats

NOTES:
1) Snubbing unit, coiled tubing unit, casing drilling, parasitic strings, and closed loop systems may be required.
2) Hydrogen Sulfide (H2S) production requires special considerations.
3) Gas and H2S monitoring systems, confined space, explosion-proof electrical equipment, electrical bonding/grounding, and wind socks should be considered.
4) Depending on fluids used and production: 2-phase or 3-phase separators (vertical or horizontal) may be required.
5) Additional lighting, fire fighting equipment, and power generation may be required.
6) Special data acquisition systems should be considered.
7) If crude oil is being considered as the UBD fluid, a HAZOP risk assesment is required.

<u>STAGE 3</u>: *WHAT IS THE BEST CHOICE*?
(Block 6)

Block 6
<u>Well Fluid Design</u> Considerations

COMPATIBILITY OF DRILLING FLUIDS WITH:

Formation lithology

- Core and/or drill cuttings data
- Log and geophysical
- Scanning Electron Microscope (SEM) and X-Ray diffraction
- Lab compatibility tests (Swelling test, shale reactivity, retained permeability)
- Data from offset wells including mud log data
- Prior drilling histories including overbalanced drill

Formation fluids

- Reservoir fluids samples
- Composition of all reservoir fluids (oil, gas, water)
- Emulsion test
- Under balanced Fluid/formation fluid stability
- Gas mixtures affecting explosion envelope
- Formation damage tests

HOLE CLEANING ISSUES

- Well bore geometry
- Rate of Penetration (ROP)
- Fluid cuttings carrying capacity
- Potential lost return zones
- Caliper (washout and/or ovality)
- Frictional effects on ECD

TEMPERATURE EFFECTS

- Liquid flash points
- Temperature profile with depth in order to have ECD profile with temp.
- Effects on surface and downhole equipment
- Stability limitations of drilling fluid

CORROSION

- Effects on both surface and downhole equipment
- Drilling gas/fluids (amount of dissolved O2)
- Formation (CO2 & H2S) gas/fluids types
- Salinity of drilling and formation fluids
- Temperature & Pressure profile
- Review corrosion control requirements
- Estimated contact time effects
- Elastomers compatibility

DOWNHOLE TOOLS

- UB method used (parasitic string, concentric string, …)
- Data transmission effects
- Hydraulics for running motors
- Logging and/or coring requirements
- Completion requirements considerations

HEALTH AND SAFETY ISSUES

- Review maximum exposure limitations of fluids and gas components
- Review equipment design specifications
    - Requirements necessary
- Determine non-existing equipment specifications necessary to meet safety standards
- Training issues
- Local safety regulatory compliance issues (Personnel & Equipment)
- Development of qualitative risk assessment /analysis
- Development of emergency response plan
- Review material transportation, storage and handling procedures

ENVIRONMENTAL AND DISPOSAL ISSUES

- Compliance with local regulation
- Compliance with operator guidelines
- Develop waste characterization profile
- Develop evaluation of disposal options (cuttings, produced fluids, drilling fluids)

LOGISTICAL ISSUES

- Water
- Oil
- Diesel
- Nitrogen
- Natural gas

STAGE 3 STEPS:

1. Determine the minimum **ECD** that provides maximum incremental increased **ROP**

2. With the optimum ECD determined in step 1, check if that ECD will still provide **borehole stability** while drilling to target zone. Recalculate ECD.

3. Determine what effect ECD calculated in the previous step will have on fluid influx and what effect this influx will have on **drilling fluid compatibility**. Recalculate ECD.

4. What effect will the ECD selection have regarding surface fluid handling, control, separation and processing. Recalculate ECD.

CHOOSE OPTIMUM ECD

5. Determine the effect on cutting removal, transfer and disposal, as well as the processing and disposal of associated fluids. Recalculate and select **optimum ECD**.

6. Take the **optimum ECD** from step 5 and determine the **type of drilling fluids** that are available (**Block 5)**

7. **Select the optimum fluid type at the optimum ECD that will provide the maximum incremental drilling performance at the minimum incremental cost**.

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Key issues to consider for optimum fluid type selection:

- Any gasified liquid will require additional cost due to surface separation on downstream side and additional cost for gas supply and compression on upstream side.
- Processing and disposal of cuttings and associated fluid will result in additional cost if non aqueous fluid or emulsion is used.
- Calculate incremental cost for all types of fluids in step 6 and evaluate additional cost versus saving in rig time and ancillary equipment cost saving for ROP.

<u>Example</u> of decision-making process based on optimum drilling performance (IADC UBO LEVEL 0 CONDITIONS)

<u>Factual Assumptions</u>:

A) Target zone with maximum matrix pressure of 8.0 ppg at 10,000 feet

B) Through drilling experience and petrophysical evaluation, it has been determined that there is a sloughing shale zone from 6000-8000 feet in which serious hole problems occur at 6.0 ppg ECD.

C) Review available drilling performance data such as offset bit records and drilling performance curves. Develop ROP vs Depth curve for well. Calculate total drilling time while drilling with selected UBD fluid to determine supply, handling, and disposal requirements.

D) The current surface equipment package on the rig consists of choke, mud gas separator, vacuum degasser, shale shakers.

E) A highly permeable consolidated 100% salt water sand is at 5000 feet with a total chloride concentration of 40000 parts per million (ppm). Pore pressure of 7.0 ppg and fracture gradient of 9.0 ppg.

F) The well is being drilled in a wildlife preservation area that requires zero discharge. All processed fluid and drill cuttings will have to be transported to disposal site with the following requirements: TPH less than 1% and total chloride less than 3100 ppm.

<u>Application of Stage 3 Steps</u>:

Step 1.

The Minimum ECD for maximum ROP is lowest possible, or Air at 0.1ppg

Optimum calculated ECD is 0.1 ppg

Step 2.

The Minimum ECD for borehole stability is above 6.0 ppg for shale. from 6000'-80O0'

The optimum calculated ECD is 6.5 ppg.

Step 3.

Minimum ECD to prevent fluid influx from sand salt water is 7.0 ppg.

The optimum calculated ECD is 7.2 ppg.

Step 4.

Any type of fluid selected will require additional processing based on zero discharge requirement addition of air, nitrogen or gas will require gas fluid separation.

Defer decision to step 7.

Step 5.

The high chloride sand should not have a fluid influx and thus increase disposal costs. Any oil based system will increase cuttings and associated fluid disposal cost. Defer to step 7.

Step 6.

Type of drilling fluids available from 7.2 – 8.0 ppg

a) Gasified liquid (Aqueous/non aqueous)
b) Oil in water emulsion
c) Hydrocarbon-based fluid

Step 7. MAKE FINAL DRILLING FLUID SELECTION THAT WILL PROVIDE OPTIMUM INCREMENTAL DRILLING PERFORMANCE AT MINIMUM INCREMENTAL COST.