Hollow Sphere
Dual Gradient Drilling System

JIP Kickoff Meeting

Dr. William C. Maurer
September 27, 2001
DOE Hollow Sphere Underbalanced Drilling Project
Types of Flow Regimes

- LIQUID
- AERATED LIQUID
- FOAM
- MIST
- GAS
Lightweight Mud

MUD

HOLLOW SPHERES

LIGHT WEIGHT MUD

1.02 S.G. 8.5 ppg + 0.38 S.G. 3.17 ppg = 0.70 S.G. 5.84 ppg
Particle Sizes in Unweighted, Water-Based Mud
(After Bourgoyne Jr. et al, 1986)

MICRONS

Solids Percentage

Bentonite
Small Hollow Spheres
Drilled Solids
SILT
FINE SAND
COARSE SAND
GRAVEL

0.01 0.1 1 10 100 1000 10,000
Centrifuge Test
Desilter Tests
Oilfield Hydroclone
(Moore et al., 1974)

- Overflow Opening (Hollow Spheres)
- Feed Inlet
- Feed Chamber
- Vortex Finder
- Vortex
- Underflow Discharge (Cuttings)
Golden State Drilling Rig Mud System
Mud Returns
Dual Gradient Drilling Systems
Hydrostatic Gradients for Conventional and Riserless Drilling
(Snyder, 1998)

- Mud hydrostatic pressure (D) (Riserless)
- Mud hydrostatic pressure (C) (Conventional)
- Fracture (B) pressure
- Seawater (E) hydrostatic pressure
- Pore pressure (A)

Surface Casing Depth
Riserless Drilling System
(Peterman, 1998)
“DGD is estimated to save $9 million per well and increase the project value by $150 to $250 million at Crazy Horse”

Andy Frazelle, BP (Wellconnected, Dec, 2000)
“In an ultra-deepwater well, the savings could range from $5 - 15 million in casing running alone”

Conoco, 2001 (Drilling Contractor, May/June)
Mudlift System

(Conoco/Hydril)
Mudlift Pumping System
Mudlift Subsea Diaphragm Pumps
Mudlift Subsea Diverter

Riser adapter

SRD housing

Return outlets
Mudlift Drillstring Valve

Flow nozzle

Three component body

Closing spring
DEEPVISION System

(Baker Hughes/Transocean)
DEEPVISION Subsea Module

10,000 ft. Pump Station

- 5-pump module station
- Size: 15’ * 17’ * 40’
- Weight: 350 kips
- Max. available hhp 4050
- ANSI 2500 (6250 psi) rated
- Standard riser joint connection
- Independent of BOP MUX control system
- Self contained power and control
DEEPVISION Drillstring Valve

4-3/4” Flow Stop Sub

- VALVE SEAT & CONE
- VALVE PLUNGER
- DISC SPRING PACKAGE
DGD Rock Removal Rates

Drilling Rates (ft/hr)

Rock Removal Rate (tons/hr)

12-1/4” Bit
Shell SSPS System
Shell SSPS DGD System
(Offshore, June 2001)

From Rig Power

Power Control

Existing Rig Pumps

Mud Processing

Water Depth

Pump Section

6 - Pumps Total

Motor & Seal

Check Valve

Nitrogen tank

Level Sensor

For Process Control

Eductor

Pump

Control Module

Element Optional

For Fluid Sep.

Control Module

Element Optional

For Fluid Sep.
SSPS Gumbo Slide & Mud/Gas Separation

- Nitrogen Tank (Back-up)
- Mud/Gas Separator
- Flowline
- Subsea BOP
- Gumbo Slide
- Cuttings Eductor
- Nitrogen Tank Cut Away View
Dual Gradient Project Participation

**MudLift**
- CONOCO*
- HYDRIL*
- BP
- CHEVRON
- TEXACO
- DIAMOND OFFSHORE
- GLOBAL MARINE
- SCHLUMBERGER

**DeepVision**
- BAKER HUGHES*
- TRANSOCEAN SEDCO FOREX*
- BP
- CHEVRON

**SSPS**
- SHELL
Hollow Sphere
Dual Gradient System
**Surface Hollow Sphere System**

- Mud Pump (Mud)
- Swivel
- Shale Shaker
- Spheres
- Mud Pump (Spheres)
- Drill Ship
- Drillpipe
- Mud & Spheres
- Mud Line and BOP
- Wellhead and BOP
- Mud
- Spheres & Mud
- Riser
- Valve
- Mud & Spheres
- Drill String Valve
- BHA
- Rock
Hollow Glass Sphere Technique

- Mixture
- Slurry
- Hollow Glass Spheres
- Mud
New Seafloor Equipment

DeepVision

Mudlift

Shell SSPS

Maurer

Nothing
Sea Water Density Mud
(50 % Spheres)

MUD

1.68 S.G.
14 ppg

HOLLOW SPHERES

0.38 S.G.
3.17 ppg

LIGHT WEIGHT MUD

1.02 S.G.
8.56 ppg
Mixture Density vs. Sphere Volume

Sphere Sp. Gr. = 0.38

Mud Weight
ppg

18
16
14
12
10

0 10 20 30 40 50 60 70

Sphere Concentration (Volume %)

Mixture Density, ppg

18
16
14
12
10
8
6
4

Sea Water

Water
Dual Gradient Mud Weights

Sea Floor

Mud weight (ppg)

Fracture Gradient

Safe Zone

Pore Pressure

10 12 14 16 18
Multiple Injection Points

Surface

Sea Floor

Valve

Sea Water & Spheres

Flow Line

Riser

2,500’

5,000’

7,500’

10,000’
Surface Sphere Separation

- Shale Shaker
- Mud
- Seawater
- Hollow Spheres
- Drill Cuttings
Large and Small Hollow Glass Spheres
Particle Sizes in Unweighted, Water-Based Mud
(After Bourgoyne Jr. et al, 1986)
Relative Particle Size (Microns)

- **50**
  - Small Hollow Spheres

- **147**
  - 100 Mesh Screen

- **300**
  - Large Hollow Spheres

- **1700**
  - Frac Sand (12 mesh)
Composite Hollow Spheres
# Composite Sphere Densities

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<th>Water Depth (ft)</th>
<th>Foam System Density (g/cc)</th>
<th>PVC</th>
<th>Thermoplastic Macrospheres</th>
<th>GRE Minispheres</th>
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Riser Buoyancy Modules
Solids Separation
DGD Sphere Separation System 1

Return Mud
2000 gpm
25% Spheres

Mud
1500 gpm +
Spheres
500 gpm

Conventional Mud System

Clean Mud 500 gpm

To Rig Pump
1000 gpm
No Spheres

To Seafloor
1000 gpm
50% Spheres

Seawater

Medium Cuttings

Large Cuttings

20 Mesh

100 Mesh

2000 gpm

1500 gpm

500 gpm

500 gpm
Hydrocyclone Separator

Mud & Spheres

Barite (SG = 4.25)
Drill Cuttings (SG = 2.65)
Hollow Spheres (SG = 0.4)
Water (SG = 100)

Barite, Drill Cuttings
**DGD Sphere Separation System 2**

- **Return Mud**: 2000 gpm, 25% Spheres
- **Mud**: 1000 gpm
- **Centrifugal Pump**: Mud
- **Special Hydrocyclone**: Spheres + Mud, 500 gpm + 500 gpm
- **Conventional Mud System**: Clean Mud
- **Fine Cuttings**: To Rig Pump 1000 gpm, No Spheres
- **Medium Cuttings** (Few Spheres): To Seafloor 1000 gpm, 50% Spheres
- **Large Cuttings**: 20 Mesh
- **Shale Shaker**: Large Spheres
- **Shale Shaker**: Medium Cuttings
- **Conventional Mud System**: Fine Cuttings

**Mesh Microns**
- 100 Microns
- 1000 Microns

**Mud 1000 gpm**
- **Spheres**
- **To Seafloor**
- **To Rig Pump**
- **Medium Cuttings**
- **Fine Cuttings**
- **Special Hydrocyclone**
- **Conventional Mud System**
- **Clean Mud**

**Shale Shaker**
- **Large Cuttings**
- **Mud 1000 gpm**
- **Mud**
- **Centrifugal Pump**

**Maurer Technology**
Effect of Spheres on Plastic Viscosity

Plastic Viscosity (cp)

- No Spheres: 12.5
- Large Spheres: 12.0
- Standard Spheres: 22.5

Water (36% Spheres)
Alternative Hollow Sphere Injection Systems
Drillstring Injection DGD System

- Swivel
- Sphere Mixing Tank
- Mud Pump (Mud)
- Drill Ship
- Drillpipe
- Mud & Spheres
- Riser
- Wellhead and BOP
- Sphere Separator
- Mud Line
- Mud
- Casing
- Rock
- BHA
Carrier Fluid Dual Gradient System

Drill Ship

Drillpipe

Mud & Spheres

Wellhead and BOP

Mud Line

Mud Pump (Mud)

Swivel

Shale Shaker

Mud Pump (Spheres)

Carrier Fluid

Riser

Injector Pump

Screen

Flow Controller

Valve

Choke

BHA

Mud

Rock
Carrier Fluid Dual Gradient System

- Return Line
- Injector Pump (Moineau)
- Choke
- Carrier Fluid
- Screen
- Carrier Fluid Plus Spheres
- Valve
- Mud
Seawater Transfer System

- Mud and Spheres
- Injector Pump (Moineau)
- Seawater and Spheres
- Screen
- Mud
- Seawater
Spreading Pore Pressure/Frac Curves Apart

- Surface
- Seafloor

Depth

Pressure

Increased Frac Pressure
Fracture pressure
Flow Drilling
Pore pressure
Curved Gradient Drilling
Conventional Deep Water Drilling

Riser

Sea Floor

Pore Pressure Gradient

Fracture Gradient

Safe Zone
Dual-Gradient Deep Water Drilling

Riser

Sea Floor

Subsea Pumps

Pore Pressure Gradient

Fracture Gradient Safe Zone
Fluid Injection Techniques

1. Concentric Drill Pipe
2. Parasite String
3. Tie-Back Casing
4. Jet Sub
Seafloor Sphere Injection

- Sea Water Density (8.6 ppg) (50%)
- Seafloor Sphere Injection 4470 psi
- Riser
- Casing
- 14 ppg (0%)
- 8110 psi
- 11,750 psi

Well Depth (ft)

Annulus Pressure (psi)
Sub Seafloor Sphere Injection

![Graph showing well depth and annulus pressure with subsea floor sphere injection data.]

- **Well Depth (ft):** 0, 5,000, 10,000, 15,000
- **Annulus Pressure (psi):** 0, 5,000, 10,000, 15,000

**Pressure Points:**
- **Riser:** 4470 psi
- **Casing:** 14 ppg (0%)
- **Sub Sea Floor Sphere Injection:** 5410 psi, 8110 psi, 11,750 psi

**Density Points:**
- **10.4 ppg (33%)**
- **14 ppg (0%)**
Sub Seafloor Sphere Injection

Well Depth (ft)

Annulus Pressure (psi)

- Riser
  - 11.3 ppg (25%)
  - 4470 psi

- Casing
  - 14 ppg (0%)
  - 8110 psi

- Sub Sea Floor Sphere Injection
  - 5876 psi
  - 11,750 psi
Lightweight Brine Drilling Fluid

Sea Water (8.56 ppg)

Salt Brine (12 ppg)

Salt Brine + 39% Spheres (8.56 ppg)
Major Questions

• Will Hollow Spheres Survive?
• Can Spheres Be Pumped Reliably?
• Can Spheres Be Separated From Mud?
• Can Sphere Circulation Be Initiated after Shutdowns?
• Maximum Sphere Concentration Achievable?
• How to Detect and Handle Kicks?
• Can Constant Seafloor Pressure Be Maintained?
• System Cost and Reliability?