TOP HOLE DRILLING WITH AIR RIGS
Top Hole Air Rig
Top Hole Drilling of Marcellus Shale Wells Has Resulted in a Total Savings to Carrizo of over $15,000,000, Involving 166,000 feet of Hole and 28 wells, Covering a Period of Eight Months.
### Typical Top Hole Well Plan

**OPERATOR:** Carrizo Oil & Gas, Inc  
**SPUD DATE:** 8/28/12  
**TVD:** 5600

**WELL NAME:** Bush 1H  
**STATE:** PA  
**MD:** 5600

**FIELD:** Marcellus  
**COUNTY:** Susquehanna  
**GL:** 1780

**LOCATION:** X=2464058.63 Y=624222.28  
**RKB:** 1792

<table>
<thead>
<tr>
<th>HOLE SIZE</th>
<th>MW, ppg</th>
<th>DEPTHS</th>
<th>FORMATION TOPS (KBTVD)</th>
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<tbody>
<tr>
<td>17 1/2&quot;</td>
<td>Air</td>
<td>750'</td>
<td>Top Tully 4,291'</td>
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<tr>
<td>12 1/4&quot;</td>
<td>Air</td>
<td>820'</td>
<td>Top Hamilton 4,411'</td>
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| 12 
  1/4" | Hammer bit | 1,800' | Top Marcellus 6,211' |
| 8 3/4" | Air | 5800 | TOLM 6,381' |
| 8 3/4" | Air | Directional S-Curve | Top Onondaga 6,511' |

**BIT PROGRAM**

<table>
<thead>
<tr>
<th>HOLE SIZE</th>
<th>MW, ppg</th>
<th>DEPTHS</th>
<th>FORMATION TOPS (KBTVD)</th>
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<tr>
<td>80'</td>
<td>820'</td>
<td>17 3/2</td>
<td>Surface</td>
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<tr>
<td>820'</td>
<td>1,800'</td>
<td>12 1/4&quot;</td>
<td>Hammer bit</td>
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<tr>
<td>1,800'</td>
<td>5,800'</td>
<td>8 3/4&quot;</td>
<td>Hammer bit</td>
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Typical Pad Spider Plan
Top Hole Rig Considerations

ADVANTAGES

Cheaper Day Rate
• $10,000 - $12,000/Day Less

Higher Mobility
• Faster Rig Up Time

Air Drilling Experience
• Greater Efficiency in Air Drilling

DISADVANTAGES

• Close Coordination of Spudder and Big Rig Schedules Required
• Permit Delays and Weather Could Affect Pad Preparations
• Depth Limitations
Problems Encountered in Surface Hole

- High Volume Fresh Water Flows
  - Impedes Hammer efficiency
  - Creates Water Storage Problem
  - Hole Instability and Enlargement
  - Can Cause Turbidity in Nearby Water Wells

✔ Solutions
  - Minimize drilling time, thus reducing water volume
  - Have adequate storage available (frac tanks)
  - Squeeze with Redi-Mix cement if necessary
Problems Encountered Below Intermediate

- Shanked Hammer Bits or Unscrewed Chucks
  - Difficult Fishing Job
  - Potential Re-Drill or Sidetrack

✓ Solutions
  - Baker Lock Backhead Threads and Chucks
  - Educate Drillers on Good Hammer Drilling Practices

- EM Tool Signal Problems While Dusting

✓ Solutions
  - Reduce Vibration by Running a Jet Sub in the BHA
  - Add 2-4 Gallons of Soap on Connections
Evolution of Drilling Practices Below 9 5/8”

Initial Drilling Practice – Down Hole Motors with Air Hammers
- **Results**
  - High frequency of shanked bits or unscrewed chucks
  - EM tool signal problems when dusting
- **Modifications**
  - Limited hammer hours to a maximum of 40 to reduce failures
  - Misting to improve signal, but reduced hammer efficiency

Subsequent Drilling Practice – Down Hole Motors with Insert Bits
- **Results**
  - Fewer problems and less trouble time
  - Slower ROPs (50 – 70 FPH)

Current Drilling Practices – Motors, Air Hammers and Jet Subs
- **Results**
  - Baker locked chuck and backhead threads on hammer bit
  - Reduced down hole failures, faster ROPs, no limit on hammer hours
Directional Bottom Hole Assembly

Well Information

<table>
<thead>
<tr>
<th>JOB NO.</th>
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<tbody>
<tr>
<td>FIELD</td>
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<tr>
<td>Company</td>
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<td>RIG NAME</td>
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<tr>
<td>COUNTY</td>
<td>Susquehanna</td>
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<tr>
<td>BHA TYPE</td>
<td>Steerable Assembly</td>
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<tr>
<td>WELL NAME</td>
<td>Frystak East 8H</td>
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7/8 2.1 RPM 55° Bit - SVY 4.45° Bit - Bend

Diagram:

- XHP x FHB O.D.=6 1/2
- DC O.D.=6 1/2 Length=31.1 TOP CONN:4 1/2 XH B
- Jet Sub O.D.=6 3/8
- DC O.D.=6 1/2 Length=30.61 TOP CONN:4 1/2 XH B
- NMDC O.D.=6 1/2 Length=30.82 TOP CONN:4 1/2 XH B
- Gap Sub O.D.=6 3/8
- NMDC O.D.=6 5/16 Length=30.79 TOP CONN:4 1/2 XH B
- 1.25 Fixed 7/8 2.1 O.D.=6 11/16 Length=27.52 TOP CONN:4 1/2 XH B
- Hammer Body O.D.=7 1/2
- Hammer O.D.=8 3/4 Length=0.4 TOP CONN: P
Hammer Bit
Lessons Learned

**Surface Hole**
- Handling Water Flows up to 750 BPH
  - Minimize drilling time, thus reducing water volume
  - Have adequate storage available (frac tanks)
  - Squeeze with Redi-Mix cement if necessary

**Intermediate Hole**
- Cost Saving Practices
  - Batch drill along with surface hole
  - No directional work
  - Run gyro survey after rig skids to next well
  - Can usually dust, improving hammer performance and reducing disposal cost

**Production Hole**
- Air Hammers and Motors can be successfully run together, resulting in faster ROPs
- Run New Hammer Bit below intermediate casing, with used bit as backup.
- Use a Shale Inhibitor to control Hamilton Shale if misting is necessary
Closed Loop Air Drilling

Air
- Cyclone
- Shaker
- Belt Press
- Flare Box
- Gas Buster
- Choke Manifold
- Well Head
- Ram BOP (3K)
- Choke Line
- Polymeric Dry Cake
- De-Watered Solids
- Cuttings
- Dirty Water
- Clean Water
- Relief Valve
- Cuttings
- Water
- 0 PSI
- 500 PSI Rated
- 3000 PSI Rated

Air/Mist
- Ram BOP (3K)
- Pressure
- 500 PSI Rated
- 3000 PSI Rated
- Vent
- In
- Out

Cuttings
- Belt Press
- Dry Cake
- De-Watered Solids
- Dirty Water
- Clean Water
- Polymer
- Solids
- Out
- In
- Relief Valve
- Flow Line
- 0 PSI
- 500 PSI Rated

Cyclone Flow Line
- Air
- Vent
- Cuttings
- De-Watered Solids
- Belt Press
- Dirty Water
- Clean Water
- Polymer
- Dry Cake
- Solids
- Out
- In
- Relief Valve
- Flow Line
- 0 PSI
- 500 PSI Rated
Air Drilled Cuttings
De-Watering Belt Press
Drilling Costs

SPUDDER PERFORMANCE

$ PER FOOT

PAD COST PER FOOT

COST BELOW INTERMEDIATE

CUMULATIVE FOOTAGE DRILLED

0  20,000  40,000  60,000  80,000  100,000  120,000  140,000  160,000  180,000

0  20  40  60  80  100  120  140

0  20,000  40,000  60,000  80,000  100,000  120,000  140,000  160,000  180,000
Questions Answered

How Can Top Hole Rigs Save Money

What were Some of the Air Drilling Problems Encountered

What were the Lessons Learned

How to Efficiently Air Drill in a Closed Loop Environment

How to Effectively Directionally Drill with Air Hammers
Best Practices

- Batch Drill Surface and Intermediate Holes, monitoring deviation but without directional control
  - No directional cost incurred until drilling below intermediate casing

- Run Gyro Surveys on each well after rig skids to next well
  - No rig time wasted running gyro

- Drill below intermediate casing with directional assembly, and a Jet Sub above the motor to divert approximately 1000 CFM, reducing hammer rotation and vibration

- Run a new, full faced diamond air hammer with Baker Locked threads. Have used air hammer as backup.

- Do not let hammer drill off at connections, but pick up off bottom to dump air ASAP to minimize bit spinning off bottom. Let hammer drill fast, keeping optimum WOB.
Top hole drilling on air with Spudder Rigs has proven to be economically attractive, saving approximately $100 per foot vs. horizontal rigs.

Air drilling top holes to KOP with one Spudder Rig has resulted in a cost savings of over $15,000,000 to Carrizo since February, 2012.

Continuing to educate our drillers, and continuing to improve efficiency of our drilling practices, will result in even further reductions in drilling costs.

Continued advancements in air drilling technology, such as shorter bit to bend motors, hammer improvements, better bit design, and in software monitoring equipment may result in drilling curve sections with Spudder Rigs, providing depth limitations are not exceeded.