Pad Design Key For Marcellus Drilling

By Robert Kuntz, James Ashbaugh, Benny Poedjono, John Zabaldano, Irina Shevchenko and Christopher Jamerson

WARREN, PA.—As in other shale and tight sands plays, drilling multiple horizontal wells from a single pad has become a common approach in the Marcellus Shale in response to the economic, real estate, water disposal, regulatory and other challenges operators face in developing the play.

However, multiple-well pad drilling makes proper surveying and anti-collision monitoring imperative. Designing, surveying, preplanning and executing successful multiwell pad drilling operations require extensive collaboration between service providers and operators.

Some of the main obstacles unique to the Marcellus Shale for all operators are the topographical features that limit surface hole locations, and water disposal and supply issues. In addition, since many of the roads in the region are restricted for heavy equipment and the area has limited pipeline capacity, drilling single wells poses significant challenges for these reasons, many operators are moving to multiwell pad drilling.

The stratigraphic nomenclature used for the rocks immediately above and below the Marcellus Shale varies from one area to another across the Appalachian Basin, but the Marcellus is a member of the Middle Devonian-aged Hamilton Group. Depths to the bottom of the shale range from 3,000 feet in eastern Ohio and the northwest corner of Pennsylvania to more than 9,000 feet in southern Pennsylvania and northern West Virginia.

Pennsylvania General Energy holds a 439,000-acre lease position in the Marcellus Shale play. In certain parts of its leasehold, drill sites have to be constructed on top of mountains by leveling the ridges of the mountains to build well locations. Operators started drilling single wells in these areas (one well bore per site), but since have moved to pads with 14 or more wells on seven-foot centers at each site.

Traditional Appalachian Basin oil and gas development has used well established conventional drilling technology and practices. Air drilling has been commonly used in the Appalachian region, which makes for a more difficult survey program while drilling, since hole control can become more challenging.

Anti-Collision Management

Since most conventional drilling projects used single vertical wells, surveying was not a priority. Before Marcellus Shale development took off, the vast majority of drilling operations in the Appalachian region utilized basic gyros and steering tools with marginal quality control on the surveys. However, horizontal multiwell pad drilling in the Marcellus play makes it critical for operators to have a good understanding of the proper surveying techniques and anti-collision management processes, as well as the differences in the gyro tools used.

In the case of one Pennsylvania General Energy-operated multiwell pad design, the specific technical requirements and drilling restrictions included drilling the 17.5-inch surface hole blind on air and surveying it after drilling to a depth of ±1,000 feet. After drilling and surveying the 17.5-inch section, a 12.25-inch water protection string was drilled with air hammers/air motors using gyro measurement-while-drilling tools to begin separation of wells on the pad. Deviations in rate of penetration are strongly affected by bit dull grading in this section, and the tool tracks are optimized using the information gained based on the penetration rate drop.

Following the 12.25-inch section, an 8.75-inch hole section was drilled on air as deep as feasible. This particular multiwell Marcellus pad was drilled with a rotary steerable system and MWD. The pad was optimized to finish the directional work in the 12.25-inch section and minimize the tangent sail angle during separation of the well bores. Rotary steerable tools and motors are susceptible to extreme drilling mechanics, including shock and stick-slip, in this laminated section.

Drilling mechanics must be monitored closely to reduce the number of bit, MWD, motor and rotary steerable system failures. Roller reamers instead of stabilizers were used to reduce the effects of stick-slip during rotation to the kickoff point. While drilling the tangent section in the 8.75-inch section, directional assemblies have experienced a dropping tendency of 3.0-5.0 degrees per 100 feet in rotation while separating the well bore for anti-collision purposes and pad integrity.

Proactive Approach

To fully maximize the potential of the well site, a proactive approach was used to design the pad for a multiwell drilling program of seven pairs of wells that targeted the Marcellus as well as other formations. Pennsylvania General Energy recognized that developing a proper pad design would minimize the risks of well collision.

The operator and contractor collaborated on the pad design to ensure that the well and financial objectives were met.
The contractor utilized its experience in the offshore drilling environment, where small-footprint, multiwell drilling programs are the norm and anti-collision procedures are integral to executing drilling projects.

The proposed pad design included a detailed surveying program to prevent well collision. The operator reviewed and agreed to the design at each stage, and both parties agreed to use a new anti-collision risk management standard for well placement (specified in SPE 121040).

The operator and contractor agreed on several criteria for the multiwell pad design. The definition of the slot grids, naming convention and bottom-hole locations optimized the corresponding surface locations to the assigned reservoir to meet production objectives for the first two phases. The first phase consisted of five Marcellus and two other well bores, and the second phase consisted of the remaining corresponding pairs.

Defining a series of “uncertainty areas” for anti-collision purposes followed the surveying program at three true vertical depths: 1,000, 2,500 and 5,000 feet. North-seeking gyro-while-drilling measurements were used to a maximum inclination of 20 degrees until free of external magnetic interference from the nearby well bores. After that, MWD surveys were utilized to drill to total depth.

Using existing drilling tools and procedures, a maximum well bore trajectory was defined from each of the slots to the center of its respective uncertainty area.

The 17.5-inch section to a TVD of approximately 1,000 feet would be drilled with air without directional control. The 12.25-inch section to a TVD of approximately 2,500 feet would be drilled with air and minimum directional control to prevent well bore collision at shallow depths.

A maximum dogleg severity of 1.25 degrees/100 feet was used and the sail angle ranged from 13 to 20 degrees. A maximum dogleg severity of 10 degrees/100 feet with a minimum negative section was used to drill the 8.75-inch section to the TVD of the targeted reservoirs.

The corresponding reservoir entry had to have 200 feet of separation distance from its pair going in the opposite direction.
Anti-collision analysis of the trajectories was performed to ensure that the well bores were properly separated to minimize the risk of well collision, and then to optimize the trajectory of each bore hole to its respective reservoir target.

**Multiwell Pad Design**

After the initial pad planning meeting with the operator, the contractor received the first draft set of surface and target coordinates with the restrictions of the surface hole location and targets to be used on each slot. These data were plotted for the preliminary pad visualization. Targets and surface hole coordinates had been assigned so that none of the planned trajectories would cross one another at any depth, while maintaining an optimum volume of total footage drilled.

Figure 1A shows the original slot map with naming conventions. The graphical size of each well bore corresponds to the size of the ellipsoid of uncertainty as defined in the survey program. Figure 1B shows the original pad design with the well bores separated from one another to their respective landing points.

The vertical section view of the original pad design in Figure 2A shows optimal surface hole locations and target assignments to ensure that targets are hit in the two horizontal reservoirs. Figure 2B is the view from underneath the original pad design, showing landing points with the negative sections layout and no well bores crossing one another at any depth.

For an accurate pad execution, intermediate (2,500 feet TVD) and deeper (5,000 feet TVD) uncertainty areas were added to the well paths. Based on well plans at those respective depths, these

**TABLE 1**

<table>
<thead>
<tr>
<th>Well Name</th>
<th>Reservoir</th>
<th>Slot Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA55-T</td>
<td>Marcellus</td>
<td>A,B,C,D</td>
</tr>
<tr>
<td>AA56-T</td>
<td>Marcellus</td>
<td>A,B,C,D,E,F</td>
</tr>
<tr>
<td>AA57-B</td>
<td>Marcellus</td>
<td>A,B,C,D,E,F,G</td>
</tr>
<tr>
<td>AB77-B</td>
<td>Other</td>
<td>A,B,C,D,E,F,G</td>
</tr>
<tr>
<td>AB78-T</td>
<td>Marcellus</td>
<td>B,C,D,E,F,G</td>
</tr>
<tr>
<td>AB79-B</td>
<td>Other</td>
<td>C,D,E,F,G</td>
</tr>
<tr>
<td>AB70-T</td>
<td>Marcellus</td>
<td>E,F,G</td>
</tr>
</tbody>
</table>
transitional uncertainty areas provided accountability for each well bore’s actual trajectory deviation from the plan without creating anti-collision issues.

Figure 3 shows the original pad design with corresponding uncertainty areas at depths of 2,500 feet TVD (red circles) and 5,000 feet TVD (yellow circles) to the landing points.

Several pad design iterations were completed after the actual surveyed surface hole coordinates were received, and after another revision of the geological targets.

Because of the permitting requirements, the operator specified which targets should be drilled from which slot option locations. Table 1 outlines the slot assignment options based on Pennsylvania General Energy’s reservoir requirements.

The final pad design was created after the phase one surface holes were drilled and surveyed. Based on actual surface hole trajectories, all wells were replanned and anti-collision was reassessed. In addition, uncertainty areas were recalculated to meet the permitting requirements shown in Table 1.

Figure 4A shows the final slot assignment. The phase one drilling campaign is denoted in red after drilling the surface hole, while the well plans for the second phase are shown in blue. Again, the graphical size of each well bore corresponds to the size of the ellipsoid of uncertainty defined in the survey program. Figure 4B shows the final pad as designed to meet the approved permit specified by the operator.

Figure 5A displays the final pad design
with the red trajectories denoting the phase one drilling campaign and the blue trajectories denoting the phase two drilling campaign. Figure 5B is the view from beneath the final pad design, showing landing points with the negative section layout of both the first and second drilling campaign phases.

This Marcellus development area is still active, with drilling ongoing in the region. The contractor and operator have sought to improve the drilling program by introducing new techniques and fit-for-purpose technology. The concept and implementation of the pad design is a step-change in how future drilling and reservoir development will occur in this area.

For this particular project, the original prepared pad design was not optimal. The permitting and surveying restrictions placed on the original design required the surface locations to be modified. The experience gained from working offshore was applied to the region to reduce the risk of collision and its associated costs. For the operator, the ability to drill multiple horizontal wells on the same size of surface footprint as a single vertical well ensures the economic viability of its Appalachian drilling and development program.