A Unique Plug for a Restricted Wellbore
Joy Blevins, SPE, El Paso Corporation; Garrett Frazier, SPE, Magnum Oil Tools

Abstract
The completion of most cased-hole horizontal shale wells requires multi-stage stimulations, which calls for some form of plug isolation between the stages. The plugs are normally composite flow-thru plugs that are pumped downhole on electric wire to the required measured depth.

This case history describes a project where the industry’s standard-sized composite plugs with a 3.85-3.92 in. outer diameter (OD) would not pass through the curved section of the horizontal wellbore with an internal diameter (ID) of 4.276 in. Small doglegs in the curved section of the wellbore presented geometrical and completion challenges. Three attempts to push the plugs through this section of the wellbore failed, resulting in the plugs getting stuck. The project faced a challenge: Could a plug be built and set in the wellbore in a timely manner that would pass through the curve restrictions, set in the production casing, withstand stimulation pressure, and still be drillable?

The project challenge was successfully answered. A new composite plug was designed that met all of the wellbore requirements and allowed a successful completion of the wellbore. The 3.25 in. OD flow-thru composite plug was set in a 4.276 in. inner diameter (ID) production casing. Altogether, six plugs were pumped down and set in the wellbore of the West Texas, University Land 39 #29-1H well. The plug met all of the required performance expectations during all stages of the completion.

This plug’s application goes beyond the standard horizontal wellbore with multi-stage stimulation requirements. The uniqueness of this plug is its ability to be modified for a variety of applications where reduced internal diameters in production casing create completion challenges below the restriction.

The details of the wellbore deviations and the final plug design solution are included in this paper.

Introduction
Multi-stage completions in a monobore wellbore have become very common over the last 10 years in the industry. Cast iron bridge plugs or sand plugs were initially used initially to isolate intervals between completion stages. With the advent of unconventional completions, composite plugs emerged and technology has advanced rapidly.

The completion and stimulation method used in the majority of these unconventional plays today is known as the “plug and perf” method. After all of the interval stages are completed, the plugs are drilled out and the wellbore production is commingled. The composite material requires less time to drill up than the earlier cast iron plugs and provides better isolation than sand plugs. The composite plugs can be solid or flow-thru. The horizontal well boom has accelerated the use of flow-thru composite plugs. It is common to pump a bottomhole assembly (BHA), which consists of a plug and perforating gun clusters, repeatedly downhole on an electric line.

Some of the problems that arise more often in horizontal completions (although not limited to horizontal completions) vary with wellbore trajectory, lateral length, casing specifications, and completion methods. Common problems that lead to restricted wellbore diameters are the over-torque of casing collars, dogleg severity, and casing buckling. All of these issues have the potential to create undesirable geometry in the wellbore, which leads to completion limitations. If the restriction is slight, the BHAs may be shortened or smaller diameter tools might accomplish the objective. In the majority of the cases, a smaller plug is needed.

Industry has long had a need for a drillable plug that will go through a restriction in casing and set in the larger casing ID. A horizontal wellbore in West Texas brought this need to the forefront again.

Case Description
The University 38 #29-1H well was drilled to a measured depth of 9,720 ft with an 8-1/2 in. bit. The horizontal wellbore was kicked off at 5,323 ft and reached its true vertical depth at 5,860 ft, as shown in Fig. 1.
While pulling out of the hole following the cleanup trip, the drill pipe stuck at a measured depth of 6,120 ft. The pipe and bit were successfully fished out of the hole, and another cleanup trip was run prior to running casing.

A string of 5-1/2 in., 17 ppf crossed over to 5 in., 18 ppf production casing was run in the wellbore to 9,094 ft. Attempts to rotate and reach the measured depth of 9,720 ft were unsuccessful. The hole appeared to have sloughed in.

The initial cased hole wellbore cleanout with a 4 in. mill on coiled tubing was uneventful, and no wellbore issues were noted. The first stage was perforated with 27 ft of 3-1/8 in. tubing-conveyed perforating (TCP) guns deployed on coiled tubing without any incidents. An attempt to stimulate the first stage was aborted after the maximum pressure of 9,000 psi was observed while pumping a low concentration of 100 mesh. The decision was made to plugback and proceed to stage two in the lateral.

A BHA consisting of a 3.92 in. composite flow-thru plug and 3-1/8 in. perforating guns, overall length of 49.22ft, was run in hole on an electric line. An attempt to pump the tools through the curve resulted in the plug sticking at 6,141 ft. The plug was set, and the perforating guns pulled out of the hole. The plug was drilled out with a motor and mill on coiled tubing, and an extensive coiled tubing wellbore cleanout followed the drillout operation.

A second string consisting of the same BHA, 3.92 in. composite flow-thru plug and perforating guns, were run in the hole on an electric line. This plug stuck at 6,530 ft. This plug was drilled out with a motor and mill on coiled tubing. Once more, an extensive wellbore clean-out followed the drillout operations.

After the third plug was run on coiled tubing, without the perforating gun assembly, stuck at 6,057 ft, the wellbore was cleaned out extensively again utilizing venturi baskets, as shown in Fig. 2. A 3.97 in. by 8.9 ft mill and pumpdown gauge assembly was machined to simulate the plug assembly. This set down and stuck at 6,052 ft.
The decision was made to run a casing caliper in the well in an attempt to identify the cause of the restriction. A 3.65 in. by 10 ft caliper tool sat down 6,147 ft and would not go through the curve. A 3.188 in. caliper tool assembly successfully passed through the curve and into the lateral. The results of the caliper survey did not indicate any significant restricted ID issues where the plugs were sticking. The overall curvature in the well was small and uniform. No severe buckling, sheared or collapsed intervals were identified. The most significant reduction in drift diameter (4.2" for a drift tool 6 ft long) occurs at a connection around 5,892 ft MD. The maximum ovality was estimated to be 3.8%. It was suggested that the plugs might be catching the edge of the pin in connection. The situation may be compounded by “P-trap” trajectory or debri in the wellbore. Torque and drag simulations indicated there should not be a problem.

However, the issue appeared to be a geometry problem or a dog leg severity complication. Longer BHAs, greater than 6 ft, with ODs greater than 3.65 in., were not going through the curve section of the wellbore. A short 4 in. mill would go through the curve without any indication of a problem.

A cased hole gyro was run on coiled tubing in an attempt to confirm this hypothesis. When the second gyro survey was compared to the first open hole survey, the comparison showed some increases in dogleg severity spots, but the differences did not appear to be large as Fig. 3 shows.
Whether the problem was a dogleg or debris in the curve, conventional completion equipment would not work in this wellbore. After reviewing several completion options, the search began for a new drillable slim plug design. The OD needed to be less than 3.65 in. and be able to set in an 4.276 in. ID casing. Furthermore, it needed to withstand stimulation pressures of least 7000 psi.

**The New Plug Design**

The solution to this challenge was met with the design of a slim 3.25 in. OD composite frac plug, shown in Fig. 4, that would pass through the casing restriction and has the ability to set and hold stimulation pressure in the unrestricted portion of the 4.276 in. ID wellbore. While the slim plug design has been around for decades, this patent-pending plug adds proprietary composite materials and aluminum construction. Furthermore, the plug has repeatedly proven to be reliable.

**The composite frac plug is unique in its ability to enable wellbore isolation in a range of environments and applications. Because of the tool’s slim OD and expansive elastomeric reach, the plug can pass through damaged casings, restricted internal casing diameters, or existing casing patches in the wellbore and set in standard casing diameters. The composite frac plug has a variety of features to enable this process:**

- Versatile applications for both vertical and horizontal wells
- Longer elastomeric element system
- Rigid core to ensure passage through the toughest of conditions
- Wireline or coiled tubing deployment
- Increased length of cast iron slips that secure plug in place
- Setting performed via a universal setting sleeve and adapter
- Positive lock-up feature to ensure lock up of multiple plugs in a single wellbore
- Unique pumpdown element design requires less fluid and pump pressure to deploy plug horizontally
To meet the industry’s variety of requirements and needs, the plug’s configuration has expanded to beyond the initial request for the West Texas well.

<table>
<thead>
<tr>
<th>TABLE 1: PLUG RANGES AND SPECIFICATIONS</th>
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<tr>
<td><strong>CASING SPECS</strong></td>
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<tr>
<td>O.D Inch (mm)</td>
</tr>
<tr>
<td>4 1/2 (114.3)</td>
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<tr>
<td>4 1/2 - 5 (114.3-127)</td>
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<td>5-1/2 (139.7)</td>
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To further address requests from the industry operators, additional configurations of this new plug are available.

**Ball Drop Plug:** After setting, the tool remains open for fluid flow and allows wireline services to continue until the ball drop isolation procedure has started. Once the surface-dropped ball is pumped down and seated into the inner funnel top of the tool, the operator can pressure up against the plug to achieve isolation.

**Bridge Plug (or Kill Plug):** This plug ensures upper and lower interval pressure isolation. It is engineered with top venting capabilities for drill-out operations.

**Flo-Back Plug:** When the pressure below the plug is greater than the pressure above, the one-way check valve will allow the two zones to commingle. The operator can independently treat or test each zone and then remove the flo-back plugs in one trip with conventional milling or drilling tools.

**Flo-Back with Bio-Ball:** Also built with a one-way check valve, this plug temporarily prevents sand or bottom hole pressure from invading the upper zone and eliminates cross-flow problems by utilizing an Aqueous-Soluble Bio-Ball sealer. After pressure, temperature, or fluid has dissolved the Bio-Ball, the check valve will allow the two zones to commingle. The operators can then independently treat or test each zone and remove the flo-back plugs in an under-balanced environment in one trip with conventional milling or drilling tools.

**Results**

Following successful lab tests, the plug was tested in the wellbore. Initially, a 3.25 in. by 4 ft dummy plug was run in the hole on braided line and pumped down through the curve to 6,759 ft measured depth. Due to the success of the dummy, the decision was made to run the plug. The plug, with gamma ray and casing collar tools, was run in the wellbore to 5,800 ft, and the pumps were brought online at 3 bpm. The plug continued in the hole to 6,021 ft, and the pump rate was increased to 8 bpm. When the plug reached 6,536 ft, the pump rate was increased to 12 bpm. After reaching the desired measured depth of 8,500 ft, the plug was correlated on depth at 8,400 ft and set. The electric line was pulled out of the hole.

The ball was dropped and pumped down the well at 4 bpm. After 147 bbls, the ball was on seat. The plug was tested successfully to 7,500 psi surface pressure.

The third stage was perforated with 3-3/8 in. TCP guns run on coiled tubing. This required two coiled tubing runs to perforate four 3 ft clusters. This stage was stimulated successfully with an average rate of 81 bmp and a surface treating pressure of 5,171 psi.

The next five stages were stimulated without any wellbore incidents. The measured depths, treating rates, and pressures are outlined in Table 2.
Due to the earlier operational issues, the plugs and perforating guns were pumped down on an electric line individually. All of the stages were treated very similarly. The first stage treated above the new plug is shown in Fig. 5.

Fig. 5—Stimulation treatment depiction of the first stage pumped with new plug in place.

Following the successful stimulation operations, the plug drillout operation commenced utilizing coiled tubing with a 2.875 in. motor and a 3.980 in. five-bladed mill. Nitrogen and foam were required due to the low bottomhole reservoir pressure of approximately 2,000 psi.

The drillout of the first three composite flow-thru plugs to a measured depth of 7,684 ft took 15 hrs. Some of this time was due to circulating gel sweeps. Large pieces of rubber and some composite and aluminum material were recovered, but no slips.

Plug junk seemed to be stacking up in the lateral and hindering the drillout progress. The BHA was changed up for the second coiled tubing operation. A 3-1/8 in. venturi junk basket and 4 in. shoe were run in the hole to a measured depth of 7,664 ft for a cleanup trip. Approximately three pounds of metal, predominantly slip pieces, were recovered. Another cleanup trip with a 3-1/8 in. venturi assembly was made to a measured depth of 7,664 ft. That trip recovered only a small amount of composite material and one metal piece.

The next BHA ran in the hole on coiled tubing consisting of 4.10 in. mill and 2.875 in. motor. The next three plugs were milled through in six hours. All three plugs required approximately two hours of milling time apiece.

While the time required to complete the coiled tubing drill out was extensive, lessons were learned. The mill should be as large and aggressive as the wellbore conditions will allow. In addition, proper fluid selection with good suspension properties for enhanced hole cleaning is essential. Subsequent mill out times of the new slim hole plugs are markedly less. Today the plugs are being milled up in 30 to 60 minutes.

**Conclusions**
Operators are often challenged by a problem similar to the case history presented in this paper. The restriction may be due other wellbore complications such as damaged casing that required a casing patch or open perforations that distorted the casing ID.

Now a new slim hole plug has presented a good solution to temporary pressure isolation below many wellbore restrictions. Due to the versatility of the new slim hole plug, the operator is not put in a position of either abandoning
potential reserves or having to choose an alternative completion method that cannot yield the best possible results. The new slim plug has proven to be reliable and addresses wellbore challenges that have plagued operators for a long time now.

References