With operators in the Eagle Ford Shale looking for alternatives to fracture stimulate the toe stage of long laterals, Andrew L. Arguijo and Lee Morford, Cabot Oil & Gas, USA, and Jason Baihly and Isaac Aviles, Schlumberger, USA, explain how a new valve design can help cut costs and mitigate risk when fracturing the first stage of shale wells without perforating guns.

The KickStart* pressure-activated rupture disc valve is designed to isolate and hydraulically fracture the lateral toe stage of a shale well without perforations and the associated expense of coiled tubing (CT), stick pipe or wireline tractors to position perforating guns.

Potential application of the pressure-activated rupture disc valve is substantial in North America’s unconventional plays, including the Eagle Ford, where high crude oil and liquids yields, coupled with attractive commodity prices, are driving an unprecedented boom.

Total liquids production in the south Texas play has risen from fewer than 21 000 bpd in 2007 to 350 000 bpd by the end of last year, according to the US Energy Information Administration. Last year alone, more than 4100 permits were issued, the vast majority for horizontal wells.
The most commercially targeted areas have a pay thickness of at least 125 ft. The average Eagle Ford lateral is now 5387 ft, an increase of almost 1500 ft in the past three years. The average stage count is up to nearly 20, with perforation clusters ranging from three to 12.

The low-clay, high-carbonate content in the extensional basin make it conducive to complex hydraulic fracturing using the plug-and-perforating technique for multiple entry points that create complex fractures at a minimal cost.

Over 75% of more than 6000 Eagle Ford horizontal wells have traditional cemented and cased laterals stimulated with the plug-and-perforation method, a cost-effective and efficient way to treat every stage except the first stage.

Perforating risks and solution
In the closed system, perforating guns have to be pushed to the first fracture stage in the toe section with CT, wireline tractor or stick pipe, creating additional expense and complicating logistics and efficiency.

Initial completion approaches included the use of a wet-shoe in which the cement is displaced to create an adequate flow path at the bottom of the completion (wet shoe) to lower costs of the pump-down plug-and-perforation process. But the process includes risks of leak paths, lack of isolation and a lack of pressure integrity verification of the casing.

Engineers set out to create a valve in the casing string that would eliminate the need for a perforating gun in the first stage. The valve would include a sleeve that could be activated by pressure to expose helical ports, or slots, to the cement. Operators could stimulate through the ports.

Various port and slot configurations were tested to assess the viability of the valve by attempting to minimise and predict fracture initiation pressures. A series of finite element analyses (FEA), mathematical models and laboratory tests were conducted. Full-scale tests were then performed in unstressed concrete cylinders to investigate how the valve’s port geometry affected fracture initiation pressures in unstressed, surface conditions.

Tool design and testing
Primary goals were to minimise fracture initiation pressure and see which port design promoted a vertical bi-wing fracture in the concrete. The tests were performed with 4 ½ in. casing and valve assemblies cemented inside concrete cylinders 36 in. in height with an average compressive strength of 4000 to 5000 psi.

Cylinders were constructed for each tested port configuration. The assemblies were pressured up until failure, or fracture initiation, and the pressure was recorded. The pressure breakdown response created by perforating guns was also evaluated against the various port configurations.

The results showed fracture initiation pressures varying from 327 psi to 1790 psi. Each port configuration had a unique effect on the near-wellbore geometry of the hydraulic fractures. A cutaway of a test with six 12 in. vertical slots with 60˚ phasing can be observed in Figure 1. The slots created a bi-wing vertical fracture plane.

Unstressed cylinder tests showed that a port configuration consisting of six 6 in. ports with 60˚ phasing provided optimum performance for fracture initiation. A 3D FEA model predicted the stress near the wellbore in tight sandstone with far-field stresses applied and determined the optimum parameters for tests under actual bottomhole conditions.

Tests were conducted using sandstone blocks. For each test, a 30 in. wide by 30 in. deep by 54 in. tall block of sandstone was placed in a tri-axial test apparatus. A minimum horizontal stress of 4000 psi, maximum stress of 5000 psi and an overburden stress of 6000 psi were applied to the block.

The base case test was constructed using 4 ½ in. casing cemented in the rock block and then perforated with a 1 ft gun with 3 spf at 120˚ phasing. One of the shots was aligned to the preferred fracture plane (PFP) to simulate the best possible alignment for the perforating gun.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Average rate (bbl./min.)</th>
<th>Average treating pressure (psi)</th>
<th>Average HPP</th>
<th>ISIP (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>65</td>
<td>6830</td>
<td>10 881</td>
<td>4562</td>
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<tr>
<td>2</td>
<td>80</td>
<td>7089</td>
<td>13 848</td>
<td>4996</td>
</tr>
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<td>3</td>
<td>79</td>
<td>6110</td>
<td>11 771</td>
<td>5007</td>
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<td>4</td>
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<td>6764</td>
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<td>4741</td>
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<td>79</td>
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</table>
A pressure of 4540 psi fractured the sandstone block with the 120° perforations. Another test using a six-slot valve phased at 15° from the PFP broke down the sandstone block at 4598 psi. The difference between the perforations and 15° helical port sleeve tests was negligible, and indicated that the valve does not require a high fracturing pressure, making it a viable completion option.

To reduce the near-wellbore pressure effects further, engineers used the calibrated 3D FEA model to analyse various port configurations. New helical ports were developed to best emulate the effect of oriented perforations in the wellbore. Based on this model, a new helical port configuration was developed and used successfully in real well applications (Figure 2).

**Rupture disc valve placement and activation**

The KickStart rupture disc valve is spaced three to four casing joints above the float shoe to align the valve with the desired toe stage frac point in the formation.

When the valve is set in place, cementing operations begin. The cementing process is performed just as if the wellbore was lined only with casing. There are no changes in the cement pumping procedure. No special cement chemistries, such as acid soluble cement, are needed. After the cement is set, a casing integrity test is performed. The valve is then activated by pressuring up slightly above the casing test pressure.

The tool is activated by increasing bottomhole pressure to rupture either one or two rupture discs positioned to block flow (Figure 3). Rupture discs can be selected ahead of time and installed before the valve is delivered to the rig or on the rig floor when casing is being run. The discs are selected based upon the sum of surface pressure and well hydrostatics. The rupture discs are manufactured in 250 - 300 psi increments, allowing for a precise activation window.

The rupture disc is typically selected to have a value approximately 500 psi greater than the desired casing test pressure. Only one disc needs to rupture for the RDV to operate. Upon rupture, a pathway for fluid flow opens to the tool’s internal atmospheric chamber. Pressure and fluid rush in, and the valve opens in a piston-like manner. When the internal sleeve slides open, the helical ports around the rupture disc valve expose the entire circumference to the cement sheath.

The hoop stress in a horizontal wellbore typically contains two weak points 180° apart in the near wellbore area. Regardless of tool orientation, one of the fracturing ports is never more than 3° from one of the minimum stress points on the hoop stress envelope. This ensures that the hydraulic fracture near the wellbore does not have far to reorient, minimising tortuosity, which in turn reduces fracture treating pressure. The helical ports allow for the cement to be broken down with ease. Fluid can then continue into the formation to create the hydraulic fracture. The total sum of all ports is 10.7 in.², equivalent to six perforation clusters 2 ft each in length with 6 spf.

The first stage is pumped through the rupture disc valve with relatively low initiation and surface treatment pressure, similar to hydraulic fractures pumped through perforation tunnels. Once the first stage is completed, economic pump down plug-and-perforation operations can commence. Alternatively, the valve does not have to be used if the operator prefers multiple perforation clusters for some reason.

A gun string with a frac plug can be pumped down and set as in any plug-and-perforation operation. No frac balls are required. The valve is rated to 20 000 psi and 325 °F. Treatments can be pumped through the rupture disc valve at rates up to 120 bbls/min. and up to 10 lbm/gal. of proppant added. The pump rate allows operators to use the rupture disc valve across a wide variety of formations types, pressures and temperatures.

**Eagle Ford Shale success**

Cabot Oil & Gas first used the KickStart valve in the second quarter of 2011. Eliminating CT-conveyed first-stage perforating gun runs, in laterals that average approximately 5500 ft with 14 to 20 stages on well spacings down to 55 acres from the field norm of 80 acres, helped reduce costs. Routine casing tests are performed to 10 000 psi. The tests typically select rupture discs that activate at 600 to 800 psi above the casing test pressure. All of the rupture disc valves have activated within 200 psi of the desired range.

The operator routinely pumped the first fracturing treatment, consisting of over 250 000 lbm of proppant at 65 bbls/min., through the RDV helical ports. For the rest of the stages, 80 bbls/min. and 400 000 lbm of proppant is common. The fracturing treatment rate was 65 to 80 bbls/min. for all wells. Some increases and decreases in the treating pressure were due to fluid type or additive changes and equal one wellbore volume pumped.

Table 1 shows the average rate, treating pressure, hydraulic horsepower (HHP) and instantaneous shut in pressure (ISIP) of the first 10 stages on the B-6H lateral. The KickStart rupture disc valve stage had similar average treating pressures, the lowest HHP and the second lowest ISIP of all stages analysed. This is proof that fracturing through a cemented sliding sleeve with helical ports is not troublesome and is very similar to other plug-and-perforation stages in the same wellbore.

Consistent fracture stimulation treatments were achieved, with more than 250 000 lbm of proppant through all of their rupture disc valves without any issues.

**Note**

*Mark of Schlumberger.*