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When is a hole more than a hole?

Many operators, especially those drilling in the shale gas plays, are finding out that there's a big difference between perforating for production and perforating for stimulation.

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Most completion engineers considering perforating options for wells intended to be put straight onto production get deeply involved in designing the "perfect" combination of entry hole size, perforation tunnel length, perforation interval(s), shot density, shot phasing, explosive charge specifications, and carrier type. They carefully consider completion fluid design, amount of hydrostatic head, conveyance technique, and whether to shoot underbalanced or overbalanced. Especially in horizontal wells, gun orientation must be considered.

Unfortunately, when shooting for stimulation, oftentimes those same engineers will say, "I'm going to frac this well; just gimme some holes in the pipe."

Considerable experience and engineering work has shown that just as much forethought should go into perforating for stimulation as goes into perforating for production. Much of this work has come from the pumping services companies themselves, who have seen their industry grow exponentially since the advent of unconventional gas well drilling. Old shale-play hands laugh and admit that in the early days, the science of stimulation amounted to, "Pump and pray." Not anymore.

More science than religion

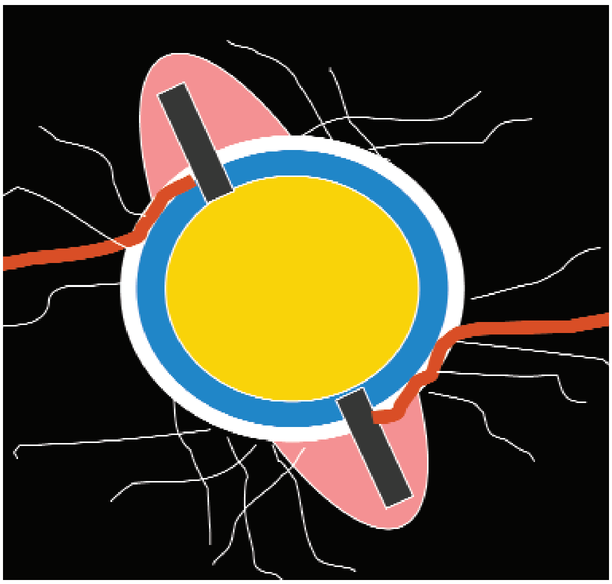
While no one is going to argue against a little prayer now and then, there are proven scientific techniques available that help operators make the perfect holes to complement a hydraulic fracturing stimulation job. Many of the perforation parameters are the same, but their order of importance is different. For example, deep penetration is not as important when shooting for stimulation as it is when shooting for production. The frac job itself will provide the penetration.

To understand how each characteristic of the perforation influences fracture stimulation success, let's begin at the beginning — orienting the gun.

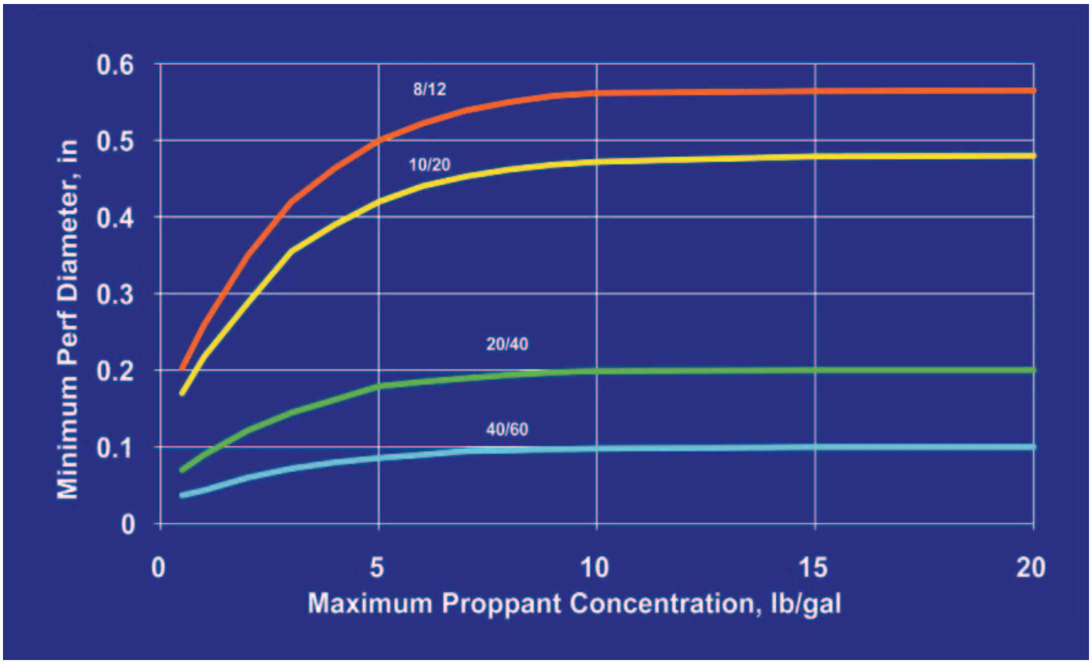
When rock fractures from the application of hydraulic pressure, the fracture tends to seek the "point of least resistance" to initiate formation failure. This point is defined by the rock's tensile strength and the direction of maximum horizontal stress. Typically the vertical stress imposed by the overburden is far greater than either the maximum or minimum horizontal stress, so fracture planes tend to orient themselves vertically and are aligned with the direction of maximum horizontal stress.

Depending upon the orientation of the well bore at the perforation depth, it may be possible to orient the perforating guns so they shoot in the direction of maximum horizontal stress. This direction can often be determined in advance through the use of acoustic logs or by mapping the orientation of natural fractures in the area. Generally, the closer the perforation tunnels align with the direction of maximum horizontal stress, the lower will be the pump horsepower required to initiate the fracture.

If by chance the perforations are aimed in a different direction than the plane of maximum horizontal stress, there is a good likelihood that the fracture will propagate around the annulus (or cement sheath in the case of cemented pipe) looking for the plane of least resistance and create a tortuous path for the proppant. The tortuosity will cause a near-well pressure drop that can result in sub-optimal fractures and premature screen-outs.



A poorly oriented perforation results in a tortuous path for the treatment as it seeks its path of least resistance (stress) to initiate the fracture. (Images courtesy of Owen Oil Tools)



Minimum perforation diameter to avoid proppant bridging is a function of proppant slurry concentration and proppant size (mesh), even at concentrations as low as 0.5 lb/gal.

Some have used a "shotgun" approach, shooting multiple perforations in all directions. In this case, the stresses from adjacent perforations can overlap, causing the entire near-well region to be stress-altered and damaged so fracture initiation is inhibited, or causing proppant to bridge off in the near-wellbore area so the entire fracture is jeopardized. Actual field experience has shown in many cases that fewer holes, made with smaller charges and oriented with the maximum horizontal stress plane, leads to lower breakdown pressures and better fracture conductivity.

Bigger holes are better

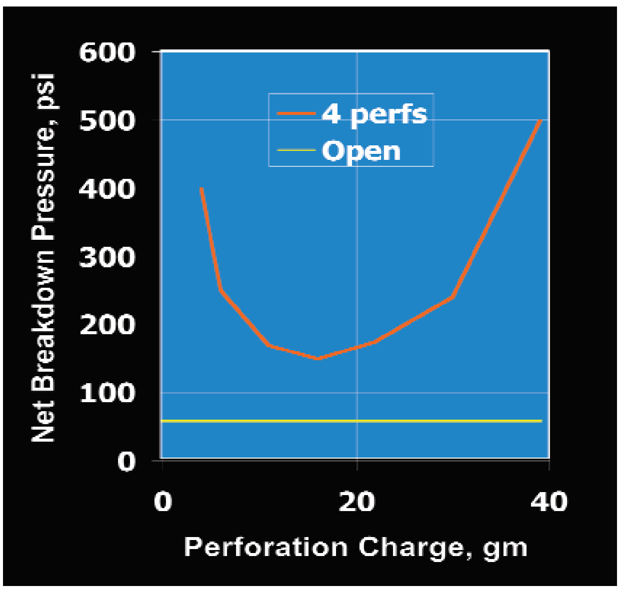
Once the guns are oriented properly, it's time to consider the optimum perforation entry hole diameter. For fracture stimulation, larger diameter entry holes are preferable. The rule of thumb is that perforation entry holes should be six times the diameter of proppant size (or mesh). Too small an entry hole almost always results in proppant bridging. Even with high liquid ratios, bridging can occur if the perforations are too small.

Penetration length is the natural question everyone asks. "How deep must the charges shoot to ensure I get a good frac?" Surprisingly, depth of penetration is relatively unimportant. For stimulation jobs, perforation diameter and explosive load are the critical factors. The frac treatment is going to produce the reservoir contact, not the perforation. If the perforations are oriented properly, if the entrance hole is large enough, and if near-wellbore perforation damage is minimized, conditions favor the generation of a good fracture. But there is still one major caveat — plugged perforations.

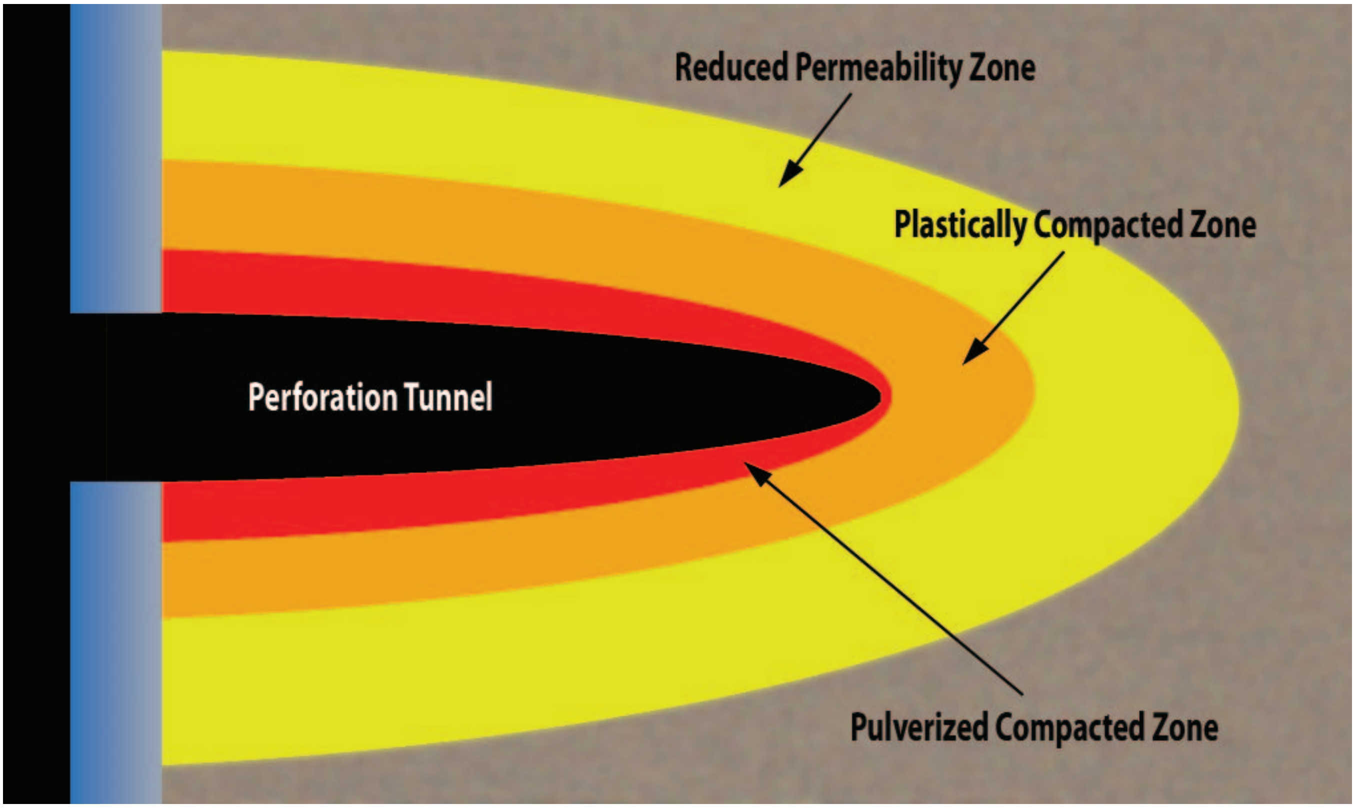
Every perforation creates a certain amount of formation damage. The perforation tunnel is surrounded by a zone of pulverized and compacted rock, then a plastically compacted zone, and finally a reduced permeability zone before the virgin formation is reached.

Fortunately, this damaged zone can usually be overcome by applying more frac horsepower. Good gun and charge selection, coupled with good perforation hydraulics, can minimize the formation damage, but there's still a major problem.

Perforating charges work according to the basic force equation — $F = MV^2$. The force acting on the target, in this case the casing, cement sheath and



Proper charge load can minimize the stress cage surrounding the perforation, minimizing the hydraulic horsepower required to achieve formation breakdown. In this case, a relatively undamaged completion is achieved using 12 gram charges loaded six to eight shots per foot.



Formation damage around the perforation tunnel can be minimized by charge selection and good perforating hydraulics. Since perforation length is not a factor in stimulation, high-powered charges that create damage can be avoided.

the formation, is a function of the mass of the particle jet and the square of its velocity. The mass comes from the decomposition of the charge liner once the explosive ignites. Most high-performance perforating charges use a tungsten compound to give the liner its mass. Unfortunately, unless the charge is properly designed, once it loses its energy the liner reconstitutes as a solid slug that plugs the perforation tunnel. This impedes the flow of frac slurry and can even turn a stimulation job into a disaster.

Intelligent perforating charges, such as the HERO and SuperHERO charges from Owen Oil Tools, are manufactured with a patented liner material that combines the benefits of a high-velocity jet with the density of a tungsten liner to create the necessary energy to get past the damaged zone, but the Owen liners also contains molybdenum (Mb), and that makes all the difference. The addition of Mb to the liner material causes it to degrade into a frangible granular form instead of a solid slug as it loses energy. With no slug to impede fluid flow, the fracture treatment can reach out into the formation, creating maximum reservoir contact, and most of the granular debris will be swept out of the perforation tunnels during clean-up following stimulation.

What's the payoff?

When perforations are optimized for hydraulic fracture stimulation, the entire job benefits. Perforation clusters consisting of clean holes with minimal formation damage and properly oriented with regard to the maximum horizontal stress plane require less hydraulic horsepower to break down. This saves money. Perforation entry hole diameters optimized for the proppant mesh diameter being pumped will not bridge over, and the absence of a solid slug of congealed liner material makes it easier for the treatment to exert maximum force on creating the fracture. Post-treatment clean-up is facilitated as is ultimate production performance. This makes money.

There's no substitute for an effective stimulation. But the first step is to ensure the treatment has the best chance for success by creating perforations that are specifically optimized for hydraulic fracture stimulation treatments. These perforations result from using an engineered gun system with charges, explosive load, and carriers matched to deliver the type and quality holes needed; with phasing, shot density, and orientation optimized to match the formation being perforated; and with charge design that minimizes formation damage and eliminates plugging. The most successful treatments start with high-quality perforations — no one wants to risk their well's production future on just any old hole in the pipe. E&P