TECHNICAL PUBLICATION

Title:	**Enhancing Matrix Acidizing with Electro-Hydraulic Stimulation**
Author:	**Mike Perri, P.Eng, Blue Spark Energy Inc.**

ABSTRACT

There are several remediation techniques available to improve the productivity of an under-producing well. The most common techniques include hydraulic fracturing, re-perforating, solvents, and acidizing. This technical overview will specifically address matrix acidizing, and how it's effect can be enhanced with electro-hydraulic stimulation.

NEAR-WELLBORE DAMAGE OVERVIEW

Many wells experience a near-wellbore reduction in permeability at some point in their life that can drastically reduce their production or injection rates. This damage, or "skin", can occur during the drilling or completion of a well, or during the production cycle of a well. The net result is decreased liquid or gas flow into the borehole. Regardless of when the damage occurs, a well producing below its potential can quickly become an uneconomical well.

CAUSES OF SKIN

Near-wellbore damage can occur at any time during the life of a well, from drilling the well through the production life cycle. Each stage of a well may have its own unique causes of skin.

Most wells are drilled overbalanced, and if the mud system is water based, there are several incompatibilities that can cause formation damage as the fluid is lost. Even formations drilled with oil-based mud systems can experience formation damage during drilling, although not usually as extensively or as often as with water-based mud.

During completion of the well, the first and most common cause of near-wellbore damage is perforating, generally due to the creation of a "crushed zone", as well as glazing due to the intense heat. Perforating in an underbalanced state can aid in reducing these effects, but usually cannot totally eliminate all skin damage.

Lastly, precipitates (scales and solids) and extremely small formation material (fines) can be created during the production phase of a well, causing formation skin, thereby reducing the permeability of the formation.

THE TRADITIONAL SOLUTIONS

Of the traditional methods of improving connectivity to the reservoir, hydraulic fracturing is probably the most successful, since a well-executed "frac" will create pathways into the formation rock that extend well beyond the near-wellbore damage created during drilling and/or completion. Doing the frac during the production phase helps connect the wellbore to the reservoir beyond any skin damage that occurred during production.

Other types of treatments include propellants or explosives. Propellants create pressures up to 20,000 psi that last from several milliseconds to several hundred milliseconds, creating fractures in the formation rock and hence pathways beyond the near-wellbore damage. Perforating – or "re-perforating" if used as a method of improving skin caused by production damage – should improve access to the reservoir as the perforation tunnels will generally extend beyond the near-wellbore damage (although perforating introduces its' own skin).

Matrix acidizing is the other commonly used method to improve productivity in damaged wells. Acid can usually dissolve the sediments, mud solids, and precipitates that plug up the pores, thus improving the permeability of the rock. In the case of carbonates, it may also aid in the formation of wormholes, small continuous channels through the rock. Matrix acidizing on its own can improve the skin value to zero or slightly negative in some cases.

ISSUES WITH THE TRADITIONAL METHODS

All methods have advantages and disadvantages, which are very dependent on budget, scheduling, safety concerns (handling and transportation), jurisdictional regulations, operational constraints (such as the need for zonal isolation), effectiveness, and environmental concerns & impact. When matrix acidizing specifically, the acid will tend to follow the path of least resistance and may therefore not always treat as large of a volume or the right areas of the formation as intended, thus reducing its effectiveness.

ELECTRO-HYDRAULIC STIMULATION AS AN ALTERNATIVE

A more unique and newer technology for improving flow due to damage in the near-wellbore area is with a form of high-pulsed power (HPP) called electro-hydraulic stimulation (EHS). EHS uses a relatively small amount of electrical energy that is amplified, stored, and then released in an extremely short time. By compressing the time frame, a large amount of power can be generated and released, creating a shock wave and a pressure pulse. These two forceful mechanisms can dislodge material in both the wellbore and the formation rock (Figure 1). Due to the speed of the energy release, tremendous power can be generated from a relatively modest energy source.

EHS tools generate thousands of repeatable, high-power pulses on each trip into the well. When

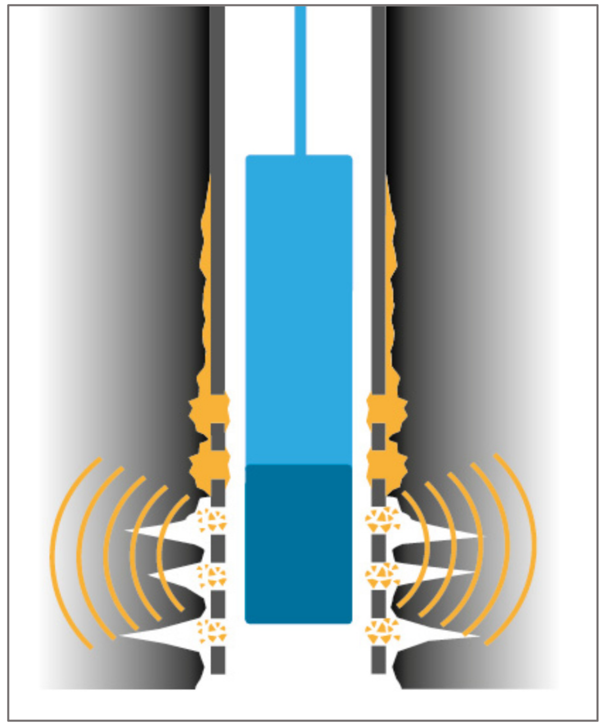

Figure 1. An electro-hydraulic stimulation (EHS) tool generates both a shock wave and a pressure pulse, causing tensile failure of geomaterials.

the acoustic shock wave interacts with a material possessing a different acoustic impedance than the liquid through which the wave is propagating (steel or a geomaterial), there is an energy reflection and/or energy absorption event. Due to the acoustic impedance difference between a liquid and a geomaterial, a tensile stress results. In general, the tensile strength of rock is only 10-20% of the compressional strength of rock. Hence, the stresses generated through this interaction are significant enough to exceed the tensile strength of most reservoir rocks, thereby causing fracturing of the formation, but are much less than the yield strength of steel, protecting the integrity of the casing and cement. The tensile strength of most organic and inorganic scales is also exceeded, causing these materials to disaggregate and hence become mobile. The cumulative effect of the repetitive shock waves (pulse delivery is repeated every few seconds) creates increasingly deeper tensile cracking in the near-wellbore, creating pathways that allow increased inflow (Figure 2). The service is designed to stimulate the near-wellbore region of a completed interval, up to 0.9 m (3 feet) from the well center.

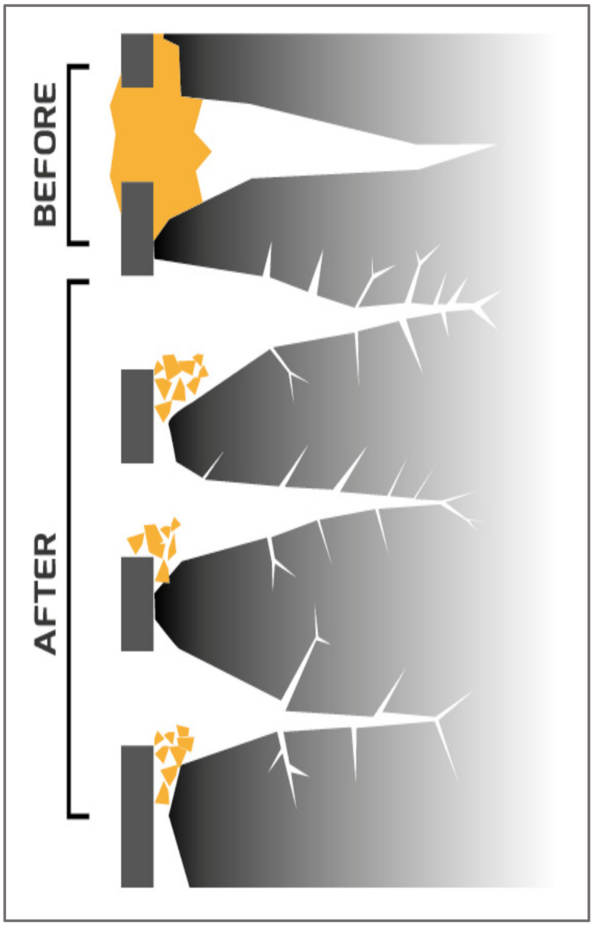

Figure 2. EHS tools cause geomaterials to disaggregate and become mobile, while causing tensile cracking in the near-wellbore.

Secondary effects of the pressure pulse from an EHS tool are cavitation and dilation. Due to the time-frame of the EHS tool pulse, cavitation occurs in the liquid immediately adjacent to the tool, creating a shock wave when the bubble of gas collapses, further creating forces on the formation rock. Dilation can also occur due to the shock wave, which can result in a realignment of the rock matrix grains, effectively increasing the pore space between the grains (Figure 3). This can allow for improved fluid flow through the pore throats, whether that be fluids being produced or fluids being injected into the reservoir.

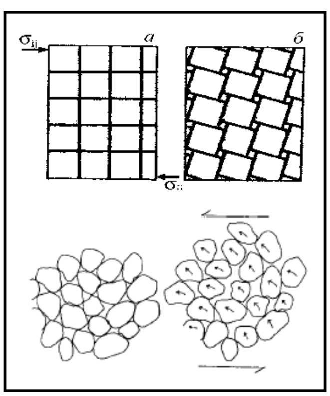

Figure 3. EHS tools produce shock-wave induced dilation. This is illustrated in a cubic shaped material in the upper pair of images above, and in matrix grains in the lower images.

DEGREE OF FORMATION DAMAGE[1]

When no damage is present, about 25% of the pressure drop takes place within 3 ft (0.9 m) of the wellbore. Because this is a small percentage of the total reservoir volume, any damage to this region may cause a much larger pressure drop (drawdown) during production and will therefore dominate well performance.

Near-wellbore formation damage tends to be shallower when it is more severe. Severe damage ($k_D/k < 0.2$) is usually close to the wellbore, within 1 foot (0.3 m), whereas moderate damage ($k_D/k > 0.2$) may occur much deeper – 3 ft (0.9 m) from the wellbore or more. Drilling solids infiltration is generally shallow (less than 1 inch); drilling fluid filtrate however can invade the formation up to 3 ft (0.9 m). Perforation damage is moderate and varies in severity according to the perforating procedure. Water injection well damage can be quite deep when moderately clean fluids are injected over long periods of time with small unfiltered solids in the fluid. Likewise, incompatible fluids or the scales being formed may penetrate deeper in the formation. Deep damage is usually more moderate but can be quite difficult to reach with reactive fluids like acid and, thus, may require deeper treatments like hydraulic fracturing or acid fracturing.

SPECIFICS OF ACIDIZING[2]

Matrix acidizing is applied primarily to remove damage caused by drilling, completion, and workover fluids & solids precipitated from produced water or oil. A matrix treatment can restore permeability by removing damage around the wellbore, thus improving productivity in both sandstone and carbonate wells. Several types of acid can be used for sandstone reservoirs, while hydrochloric acid (HCl) is generally used for carbonate reservoirs. In carbonate rock, HCl also enlarges the wellbore or tends to bypass damage by forming wormholes, small, continuous channels usually around 2 to 5 mm in diameter. As a result, the permeability increase can be much larger in carbonates than in sandstones. In radial flow, wormholes form a dendritic pattern, like the roots of a tree. Gadanski[4] developed a practical model for wormholing during matrix acidizing in carbonates, which shows that practical limits for effective penetration of HCl varies from about 1 to 5 ft. Penetration is limited by injection rate and volume. The maximum injection rate reached is a function of the carbonate permeability.

In carbonate rock, calcium carbonate scale (CaCO3) can be treated with HCl or organic acids, but calcium sulfate scale (CaSO4) must be converted first before being treated with HCl, or alternatively can be treated with ethylene diamine tetra acetic acid (EDTA). In either case, both converters and EDTA can be more effective if there is more surface area for them to work on.

If there is no near-wellbore damage, a matrix treatment seldom increases natural production more than 50%, depending on the size of the treatment and the penetration depth of live acid (unreacted acid).

CHOOSING ACIDIZING CANDIDATES[3]

A good matrix acidizing candidate is any well producing from a formation with permeability greater than 10 md where the permeability in the near-wellbore or near-perforation region has been reduced by mineral scale. If near-wellbore damage (generally damage up to 3 ft) is the cause for poor production, the well is typically a good candidate for acidizing.

Several methods can be used to evaluate the presence and/or severity of damage:

- production history plots (e.g. sudden change; slope change)
- offset well comparison (geology; production)
- pressure buildup tests
- well performance analysis
- physical evidence (water analysis, borehole cameras, scale on pumps and tubulars)

In waterfloods, the effective reservoir pressure and the injection rates into adjacent wells are also important in determining whether production declines are due to near-wellbore damage.

ENHANCING ACIDIZING WITH EHS

Acidizing is a very effective way to reduce near-wellbore damage, but the unfortunate fact is that acid takes the path of least resistance when it is being pumped. The path of least resistance will tend to be the pathways that are already contributing to the majority of the flow, not those that are the most plugged off. Hence, the acid may not penetrate where it is most needed. Acidizing using zonal isolation will generally give better results than bullheading, but is more expensive.

The well documented effects of electro-hydraulic stimulation include the dislodging of material plugging the pores, the fracturing of geomaterials (the creation of “micro”-fractures), and the dilation of the rock matrix grains. All three of these effects contribute to increased permeability, which increases the effectiveness of acids, converters, or mutual solvents. These fluids will have the opportunity to flow into the pathways that have been opened by EHS, treating more surface area of the formation rock that has skin damage associated with acid soluble solids.

CASE STUDIES

In the first case study (Figure 4), an operator in Eastern Europe used EHS on a well as an alternative to bullheading acid. Acid application was the normal remediation method utilized, but had not been effective the last two attempts on this well. Implementation of an EHS stimulation resulted in a doubling of the oil production, when

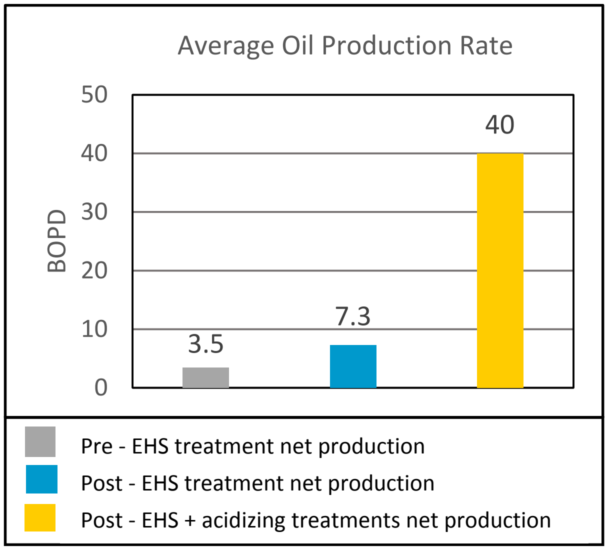

Figure 4. An Eastern European well treated with EHS and then treated a month later with acid.

averaged for one month. At that time, the operator decided to acidize the well, resulting in a further 5 times increase in production. In total, the oil production increased over 11 times the original rate, due to the effectiveness of the matrix acidizing being enhanced by the electro-hydraulic stimulation treatment.

In the second case study (Figure 5), an operator of an oil-producing shale well in Western Canada decided to try EHS as an alternative for removing calcium carbonate scale. Acid treatments had previously been found to have minimal effect on the scale. The average oil production after treatment went up 166% (for 45 days), while water production decreased 40%. At that time, the operator decided to acidize the well, increasing the average oil-production over 220% further (based on 53 days production). Water decreased another 90%. In total, the oil production increased to 6 times the original rate due to the effectiveness of the acid treatment being enhanced by the EHS treatment.

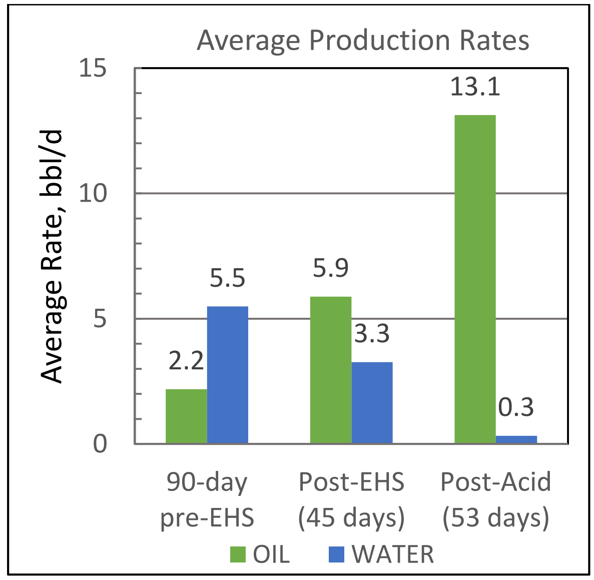

Figure 5. A Western Canada oil-shale that was acidized after undergoing an electro-hydraulic stimulation 45 days earlier.

SUMMARY

Matrix acidizing can be a very quick, efficient, and cost effective method of improving well performance that has declined due to near-wellbore damage caused by perforating and/or scale. Its effectiveness is limited however due to the fact that a fluid being pumped can and usually does follow the path of least resistance.

Complementary electro-hydraulic stimulation can greatly enhance the effectiveness of acidizing by increasing the volume of the reservoir rock that the acid can reach. This is done through the removal of material that is obstructing the pores, the creation of micro-fractures, and the improvement of porosity due to the dilation effect.

Actual field results have shown oil production increases from 6 to 11 times the initial rates when acid was preceded by EHS, compared to 2 to 3 times the improvement when EHS or acid were used individually.

ADVANTAGES OF EHS IN CONJUNCTION WITH MATRIX ACIDIZING

- No mechanical isolation of zones is required
- Safe, low risk operation, as no explosives, flammables or extreme surface pressures are required
- Creates near-wellbore micro-fracturing of the matrix rock, creating new pathways for flow
- Minimal vertical growth of fractures, reducing the risk of communication to water zones
- Volume of influence is not restricted to path of least resistance, due to the time frame of the pulse

OPERATIONAL ASPECTS OF EHS

- Fast deployment on wireline (mono or multi-conductor cable), utilizing a small footprint on the lease
- Fluid is required in the borehole, covering the zone to be stimulated
- Will work in open or cased hole, with no risk to the formation rock integrity or to casing & cement
- Can be deployed in vertical, deviated or horizontal wells (using a wireline tractor or e-coil on the latter)
- Lithology independent stimulation (clastics or carbonates)
- Precision tool placement enables selective treatment of only the desired intervals
- Works for both producing and injecting wells

NOMENCLATURE

k_D = damaged formation permeability, md

k = virgin formation permeability, md

REFERENCES

[1] SPE Petroleum Engineering Handbook, Volume IV, sections 7.3, 7.5, 7.11

[2] SPE Petroleum Engineering Handbook, Volume IV, sections 7.4, 7.12

[3] SPE Petroleum Engineering Handbook, Volume IV, sections 7.4, 7.7

[4] Gadanski, R.: "A Fundamentally New Model of Acid Wormholing in Carbonates", SPE 54719

CONTACT INFORMATION

For further information on Electro-Hydraulic Stimulation, please contact Blue Spark Energy at 1-855-284-1568 or info@bluesparkenergy.com