DHFS technologies, LLC
Production Stimulation

Well Intervention and Stimulation Treatment Comparisons

The fluidic oscillator was designed to treat and correct near wellbore damage of all types. This tool can be used in remedial workovers and as the primary stimulation method of high permeability formations to restore and increase the conductivity of the formation. The experience gained from thousands of treatments has proven that the ***True Fluidic Oscillator (TFO)*** is superior to all other tool designs and methods and in many ways is comparable to hydraulic fracturing treatments. The following discussions illustrate some of these comparisons. While this is not a complete discussion of the pros and cons of this technology by any means, it does give a general summary regarding the potential of the true fluidic oscillation technology.

Fluidic oscillation started as a comprehensive method to remove skin damage from new perforations and has evolved into a complete treatment system that can incorporate other tools as well as fracturing techniques.

Hydraulic fracturing treatments, "Frac" jobs, have become the industry standard in many areas for correcting fluid entry problems and prior to the invention of the true fluidic oscillator, frac treatments were often seen as the most effective and "necessary" solution to the problem at hand even though they come with a high price tag.

Modern frac jobs have become so highly engineered and complex that input from engineers in the production company office is many times not solicited during the design phase when it is most critical and has led to the widespread application of fracturing treatments around the world, sometimes with little thought as to the applicability.

Working with a formation with very low permeability such as "tight" (< 0.1 md) sands, frac treatments are usually necessary to establish economical production, however, there are many formations around the world that have relatively high permeability. Until the advent of the fluidic oscillator technology, it appeared prudent to order a frac job which in reality breaks through and bypasses the damage rather than re-establishing the flow path by removing the restrictions to production.

When dealing with moderate to high permeability or naturally fractured formations, using the true fluidic oscillator has proven to be extremely successful in establishing commercially economical production rates, in some cases surpassing frac rates, by re-connecting the perforations with the reservoir, opening clogged formation pore spaces and removing the near wellbore formation damage created during the drilling, completion, and production phases.
The ***TFO*** tool system is designed to remove this damage and enhance the native permeability found in the formation. Fluidic oscillation treatments have been performed that have resulted in higher initial production rates as compared to frac jobs. After one year, these same treatments are still producing oil at a higher rate compared to wells that were treated by hydraulic fracturing. The key difference is that the Fluidic oscillation treatment removes the material that restricts production instead of bypassing it.

Ball Outs
"Ball outs" are often performed to prepare the well for hydraulic fracturing. Ball sealers are injected into the treatment fluid and pumped down hole to seal off the perforations and divert treatment fluids from one perf to another. The problem is that the perforation must be taking fluid for a ball to flow into the hole and seal it off. The high pressures often associated with these operations can put undue stress on the well tubulars. These high pressures can also lead to the breakdown of the cement sheath behind the pipe, which isolates the perforations from each other. If communication is established between perforations it is often impossible to break the entire set of perfs. Tracer logs have shown that typical breakdowns using ball sealers open only 70% of the existing perforations. Wells that have high shot densities (4spf or >), existing perforations or bad cement bonds are often poor candidates for these treatments due to communication between the perfs.

Rock Salt, Unibeads, Benzoic Acid Flake Diverters
These materials are used to divert fluid flow from one perforation or section to another. They can also be used to divert fluid within the formation.

Pin Point Injection Packers, Packer & Bridge Plugs
These methods rely on direct hydraulic pressure to break down and open the perforations. At best they bypass the damage by creating a tip fracture that extends out from the end of the perforation tunnel. At worst they break down the cement bond behind the pipe and lead to communication between the perfs without establishing communication between the wellbore and the formation.

The above methods are most often used in conjunction with acid and acid/solvent blends. A very important rule that must be remembered (but is often forgotten) during these treatments is that under normal conditions, fluids under pressure will always take the path of least resistance. That path may lead into the desired formation or it may not.

This can cause expensive problems in later completion and production operations. It is also not uncommon to reach and exceed the maximum allowable pressure limits and put undue stress on the pipe in the well. This often leads to pipe failure. Another common practice in the industry is to "bullhead" acid or chemicals down the tubing to the perfs or open hole. Bullheading the fluid means to just pump it down the well's tubing. This is only sometimes effective when producing interval is very small (1' - 5'). When the interval is greater than this it is difficult to pump the fluid fast enough to create a pressure differential across the perfs which will in turn cause the fluid to be diverted across the entire interval. In most cases what happens is that the perfs that are already open take the fluid and the perfs that are plugged are not treated. This results in a very inefficient treatment.

Another common practice is to "dump" chemicals down the annulus of the well as the treatment. The only good thing that can be said about this type of treatment is that it is very easy to do. By utilizing oscillating pressure waves the fluidic oscillator is able to "gently" breakup and remove the damage that restricts the near wellbore area. The powerful combination of the oscillating pressure waves, chemical reactions and the acoustic streaming induced by the tool enables the fluidic oscillator to maximize the natural permeability of the desired formation. It has been extremely effective for stimulating formations that have frac gradients < 1.0 and is useful in aiding the stimulation of formations with frac gradients >1.0. The lower pressures involved in a fluidic oscillation treatment place minimal stress on the well's tubulars. The fluidic oscillator is moved across the desired interval during the treatment to ensure that the entire interval is opened up. The acoustic streaming induced by the oscillator allows the treatment of the entire interval even after a portion of the formation has been opened.

Jet Nozzles, High Velocity Tools
These tools rely on the direct impingement of a fluid stream on the desired target (scale, etc.) in order to work. While these tools can be quite effective at cleaning out pipe or blasting holes in buckets of cement, they have a limited effect on formation stimulation. The standoff, or distance, between the jet nozzle and the surface to be cleaned is critical and the greater the standoff, the less effective the jetting is. The effective jetting distance is approximately 8X - 12X the diameter of the nozzle. When jet nozzles are used to clean out wells they are normally very effective at cleaning the inside of the production tubing as the distance from the OD of the tool to the ID of the tubing is generally within this effective jetting distance. When these nozzles are run through the tubing and under the packer into the well's casing, the standoff between the casing (open hole) and the nozzle greatly exceeds the operational parameters of the nozzle. It is possible to increase effective distance to some degree by modifying the fluid properties and/or increasing the pump pressure. The actual benefits derived from these attempts are minimal. What often happens is that the nozzle bores a hole through whatever deposits are blocking the pipe with no effective treatment of the formation. There are jet nozzles that rotate to increase the cleaning action but they are still limited by the standoff off the nozzle.

The fluidic oscillator is not affected by standoff. By using oscillating pressure waves instead of direct fluid impingement, a 1.25" OD fluidic oscillator has successfully reestablished water injection into a wellbore with an open hole section that was at least 36" in diameter.

Pulsed Jets
Over the years there have been numerous attempts to use pulsed jets for near wellbore treatments. The idea was (is) to create cyclic pressure waves through the "on-off" pulsing of nozzle. This idea, at first glance, seems to duplicate the effect of a fluidic oscillator. However, the tools that produce pulsed jets through mechanical interruption or excitation of the fluid flow also suffer from high-energy losses and severe mechanical wear. The inefficiency of these nozzles is a result of the incremental opening and closing of the discharge ports.

Unlike pulsed jets, the ***TFO*** has no moving parts. A basic law of physics was used in the design of a true fluidic oscillator. This law is: *Force = Mass x Acceleration.* The unique internal design changes a constant flow to an "on-off" flow. The pressure pulse is created by the inertia of the fluid as it leaves the tool body. The exit velocity of the fluid is considerably higher than the fluid velocity within the wellbore. The energy contained within this fluid stream is "dumped" into the wellbore fluid as it slows down. This energy moves through the wellbore fluid as a pressure (shock) wave in a spherical fashion and impacts the near wellbore damage. This energy wave dumps its energy as it contacts the scale or formation causing mechanical disruption of the damaged area. The design of the treatment enables a useful volume of fluid to be pumped through the tool within the pressure limitations of standard oil field equipment. Another fact of life in the industry is that the smallest ID in the well's tubulars dictates the maximum OD of any tool run into the well. A fluidic oscillator is the first and only tool on the market that is not restricted by this fact. In theory, the scalability of this oscillator design (while still maintaining the ability to do useful work) can range from microscopic to the size of a large building.

Cavitation Tools
This type of tool has been around for years. The most common form of these tools is the "self- exciting jet nozzle". These designs rely on the internal structure of the tool to generate cavitational flow. When this cavitational flow exits the tool, the collapse or "implosion" of the entrained bubble vortices creates high-pressure impulses that can be used to remove scale and other forms of damage. Another version uses swirling cavitational flow within the nozzle to temporarily shut off the flow of fluid through the nozzle and thereby create an oscillating flow. This oscillating flow in turn creates the pressure pulses within the wellbore fluid. While this type of tool can be very effective at shallow depths they are hampered by one

inescapable fact. This is that hydrostatic pressure inhibits cavitation. When the hydrostatic pressure on the tool is increased, the formation of cavitational flow is reduced. For any tool size there will be a depth at which it will cease to function as it was designed. This depth can be affected to some degree by modifying the fluid properties. Lab testing and field use has shown that a 1.25" OD cavitational tool has a depth limit of approximately 2,500'. A 1.25" OD fluidic oscillator has been used to successfully clean out scale at depths of 27,000'.

Frequently Asked Questions

Q. Is this tool a jet tool?

A. No! Jet tools depend on fluid impingement to clean. Unless the fluid jet hits the target with adequate force, it will not clean it. Jet tools are also limited by standoff from the surface of the nozzle o.d. to the i.d. of the tubular (hole) to be cleaned. This can be a major problem when working under a packer. The ***TFO*** utilizes a fluidic switch to create oscillating pressure waves within the wellbore fluid. These waves move through the wellbore fluid in a spherical fashion and “dump” their energy when they contact the formation. The fluid exiting the fluidic oscillator is used to clean out in front of the tool and the pressure waves clean to the sides.

Q. What is a fluidic switch?

A. A fluidic switch is a device that diverts fluid flow non-mechanically. Flowing fluids have a tendency to preferentially attach to a nearby surface and remain attached thereto until the fluid stream is disturbed. A stream splitter in the fluidic oscillator is designed to cause the fluid flow to adhere to and flow down one passageway, while also creating enough of a disturbance in the fluid to cause the flow to switch to the opposite passageway. As long as the flow rate through the oscillator is above the activation rate for that switch, the flow will cycle “on and off” between the two outlet ports. The fluidic oscillator uses a bi-stable design based in part on the Coanda effect. The oscillator uses this “positive pulse” design to guarantee the creation of the fluid “slugs” used to generate the pressure pulses/waves.

Q. What is the magnitude of the pressure waves created by the action of the fluidic oscillation Tool?

A. There are several approaches that can be adopted to estimate the magnitude of the oscillating pressure waves. Our estimates of these pressure increases range from 1,000 psi up to 1,500 psi. Increasing the pump rate does not increase the magnitude of the pressure wave as the relative velocities within the tubing and wellbore do not change. The effective power of these waves can be increased by an increase of hydrostatic pressure or back pressure on the tool.

Q. Can you use this tool in horizontal wells?

A. YES! Near wellbore formation damage is a problem that plagues the oil industry. Horizontal wellbore's are no exception and in fact are even more susceptible to damage. In the case of new horizontal wellbores, most of the normal damage that occurs stems from the mechanical damage incurred during drilling (crushing and compaction of the rock and release of fines) and from the drilling fluids used. New drilling fluids and techniques can substantially reduce the damage from drilling fluids but cannot reduce the physical damage from drilling. Extensive research is currently being conducted to better understand the distribution of, and type of, damage found in a horizontal wellbore. The use of the ***TFO*** tool system in the stimulation of horizontal wells is a significant improvement over conventional methods. The tool system utilizes a bi-stable fluidic oscillator based in part on the Coanda Effect to generate oscillating pressure waves within the wellbore. A common method of stimulating production in horizontal wells is to place perforated subs at selected intervals in the wellbore and pumping acid down the tubing. Inflatable packers are sometimes used with this method in an attempt to ensure the correct placement of the acid and to ensure "breakdown" of the desired areas. In formations that have low porosity and low permeability (otherwise known as tombstones), this can be a successful stimulation provided there is no communication around the inflatable packer.

Another method is to bullhead the acid (or other fluid) down the tubing, with or without a packer at the end of the tubing, and depends on hydraulic pressure or chemical reaction to open up the permeability. It is important to remember that unless influenced by other factors, fluid will always take the path of least resistance. At less than fracturing pump rates, it is possible to pump an entire job into a relatively small portion of the pay zone. Diverting agents must be used to try to ensure that the entire interval is open and capable of producing.

The above methods may be satisfactory for completing a vertical well with 10 feet of perfs but in a horizontal wellbore these methods will not adequately stimulate the formation. The use of coiled tubing to place the acid across the proper intervals is an improvement but this method still has a lot of the inherent problems associated with the conventional methods discussed above. The use of conventional jetting nozzles to enhance the stimulation is an improvement but suffers from the inherent basic problems with fluid jets. The "standoff" of a jet is critical and is affected by the position and size of the pipe within the wellbore. In general, a fluid jet must directly impinge on the target surface in order to be effective in cleaning.

Q. Is there any benefit from the acoustics' generated by the tool?

A. Yes. The beneficial effects of the acoustic energy generated by the fluidic oscillator are produced through, a) the oscillating pressure waves that lead to physical disruption of the formation damage, b) the fluid flows induced by acoustical streaming and c) the enhancement of chemical reactions through greater surface area contact. Acoustic streaming is characterized by steady rotational flow occurring as a result of the interaction of acoustic waves with physical properties in homogeneities in a fluid, such as smooth boundaries and solid particles. Fluid agitation caused by acoustic streaming is not as violent as that caused by cavitation, but streaming is very effective for liberating particles attached to surfaces. This phenomenon is believed to be the mechanism by which the fluidic oscillator is able to effectively increase the near wellbore permeability of a borehole. During the clean-out and initial stimulation treatments of a wellbore, the oscillating pressure waves break up the filter cake and the crushed zone around the wellbore (perforations). The streaming flows remove the plugging fine particles from the pore throats of the rock thus restoring the natural permeability of the formation. Studies have suggested the possibility that even the native particles and fines may be removed which increases the effective permeability of the near wellbore region. Experiments and field usage show that a significant increase in the flow capability of the near wellbore is possible using water only. The initial cleaning of the wellbore prior to acidizing will greatly enhance the acid job.