DEEP PENETRATION COMPLETION TECHNIQUES USING LIQUID JET CUTTING

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ABSTRACT

Two methods that employ a pumping system operating at 10,000 psi (69 MPa) and 20 to 30 gpm (.08 to .12 m3/min) to penetrate through well casing and radially into the formation up to 10 ft will be described.

This is a downhole application of liquid jet cutting technology that is also used in mining, manufacturing, and industrial cleaning. The processes utilize a clean completion fluid, compatible with the formation of interest, to mechanically cut through the well casing and then jet cut or erode a tunnel out into the formation. Depth of penetration depends upon the type of tool used and the type of formation encountered. A description of the equipment, operation procedures and applications will be covered.

INTRODUCTION

Often the most difficult problem encountered by production engineers once a well is drilled into a potentially productive oil or gas reservoir is how to create and maintain an effective flow path from the reservoir to the wellbore. The problem is often compounded by such factors as drilling and cement damage, pore plugging, poor primary cement jobs, perforating damage, ineffective zone boundaries, etc. These obstacles not only complicate the initial completion of the well, but have to be dealt with during subsequent workovers and throughout the productive life of the well.

In many cases the traditional completion or workover methods that have been in common use for many years will allow an operator to produce from or inject into the target zone without the need for additional technology. As time goes on, however, producers more often are forced to look at alternate methods and technologies to efficiently draw hydrocarbons from smaller, less prolific, and more troublesome reservoirs that hold much of the oil and gas in North America.

Penetrators, Inc. has designed, developed and put into commercial use two completion tools that utilize liquid jet cutting to provide producers with an improved alternative to producing these reservoirs. The concept of a "Penetrator Tool" was born of a need to create the all important flow path from reservoir to wellbore, be it vertical, directional, or horizontal, cased or open hole, in a manner that would be less damaging to cement integrity and would result in the construction of large diameter, clean, deep flow tunnels into the formation rock. The advantages of tunnels of this type are obvious given the problems that must be overcome in order to allow efficient drainage of hydrocarbon reservoirs into a wellbore.

The Penetrator system was conceived in Texas and Louisiana in the mid 1980's, prototype tools were built and tested, and eventually a commercial version of the equipment was introduced in Texas in 1988. Since that time the downhole tools have evolved from a single design into two distinct tools which utilize a high pressure liquid jet to create penetrations into reservoir rock in many different applications. The Penetrator system is now in common use in the U.S. and Canada.

Initially the Penetrator system was used almost exclusively to attempt to reach past the damaged or invaded zone in problem wells in which all other methods had failed. The success rate in this application has varied due to the many other factors influencing these badly damaged wells. Although the system is still commonly used in this regard, it is also now used in applications that are not "last ditch" efforts. Many operators now use this technology on new completions to give their wells the best chance at long term productivity or view the Penetrator system as an alternative to conventional workover methods. Although cost will often be a determining factor in selecting a completion or workover method, the Penetrator system gives the production and completions engineer an additional technique in dealing with downhole production problems.

THE NEED FOR A PENETRATOR TOOL

Some of the more common problems encountered at the interface between the reservoir and the wellbore can be listed as follows:

- Most new wells are damaged to some degree by the invasion of drilling fluids and cement in the near wellbore area. In many cases perforations do not reach beyond the invaded zone of the surrounding wellbore.

- During completion and production, the migration of formation fines can plug pore throats near the wellbore.

- Production often results in the deposition of scale, asphaltene, or paraffin deposits at the perforations.

- The restrictive "bottleneck" between the reservoir and the wellbore (perforations) results in high drawdown pressures and contributes to water or gas coning.

- Weak zone boundaries often will not allow the stimulation that may be required to enhance production.

- Poor primary cement jobs or cement that is damaged (often by perforating) makes proper stimulation impossible and very likely will result in zonal communication during production.

- Perforating leaves a compacted zone around the perforation tunnel and leaves explosive debris in the tunnel; both can reduce or eliminate permeability near the wellbore.

- Bigger explosive perforating charges, designed for deeper penetration, can cause more damage to the cement and casing.

- Acidizing, even at low pressures, can migrate out of zone, seeking the path of least resistance which may be through a channel in the primary cement to underlying water.

ADVANTAGES OF DEEP, CLEAN PENETRATIONS

- Easier to maintain over time, less likely to plug-off.

- Non-damaging to cement, casing, or formation - no debris or compacted zone in or around the tunnel.

- Lowers drawdown near the wellbore thereby reducing coning.

- More efficient than perforations so fewer are required; allows staying further away from water or gas zones.

- Greater opportunity to intersect natural fractures near the wellbore.

ADVANTAGES OF LIQUID JET CUTTING OF ROCK

- Removes formation rock rapidly by erosion instead of compacting it with an explosive jet.

- Flushes cuttings out of the tunnel with return fluid from the jet cutting.

- Allows the placement of solvents or acid selectively into each penetration.

Fluids compatible with the formation and required for certain applications can be used:

- Normally use KCl, produced water, brine water, crude oil, diesel, or frac oil.

- In carbonate reservoirs, HCl or acetic acid can be used.

- In sensitive gas zones, methanol/water can be used.

- If penetration past damage is the only concern, the fluid should be clean, non-damaging, and suitable for jetting.

- An acid and/or solvent can be used for scale, paraffin, or asphaltene problems.

THE LANCE PENETRATOR TOOL - "LPT"

Tool Description

This tool, based on the original design, produces deep penetrations with liquid jet cutting technology. The tool creates one hole at a time up to 10 ft. (3m) long x 1/2 to 1 in. (13 to 25 mm) in diameter in the formation rock. The hole in the casing is 1.25 to 1.38 in. (32 to 35 mm) in diameter. 5 to 10 penetrations are typically made during a single descent into the well. The maximum O.D. for 4.5 in. (114.3 mm) casing is 3.75 in. (95.25 mm) and for 5.5" (139.70 mm) and larger casing, the maximum O.D. is 4.5 in. (144.3 mm). The overall length of the tool string will range from 54 to 61 ft. (16.5 to 18.6 m). The tool consists of 3 main sections (control, lance, and punch sections) plus an anchor, filter, and a circulating valve in the downhole assembly, see Figure 1.

The control section is a pressure actuated valve that extends and retracts the lance and punch and directs flow to the jet nozzle. At pressures below 6500 psi (45 MPa), it directs the hydraulic pressure to "retract" the punch and lance into the tool and hold them retracted. At pressures between 6500 to 10,000 psi (45 to 69 MPa), the control section directs the hydraulics to "extend" the punch and lance and also provide flow to the nozzle on the forward end of the lance. The lance section is a long stroke double acting piston assembly that extends and retracts the lance and provides flow to the nozzle that cuts the tunnel in the formation rock using liquid jet cutting. The punch section is also a double acting piston that extends and retracts the hardened steel punch that punches through the well casing to allow the lance access to the formation. The lance passes through the punch to ensure passage through the hole in the casing.

The anchor isolates the tool string from movement as the workstring is pressurized to operating pressures. The filter traps any particles that are in the workstring. The circulating valve allows for circulation before, during or after the job for pickling, reversing, or draining the workstring.

How the Jet Cuts

The jetting nozzle for the Lance Penetrator Tool is designed to cut a short wide path for the lance to pass through so that the nozzle may advance continuously as the jet cuts, maintaining a minimum standoff distance between the nozzle and the rock face. This nozzle cuts most efficiently within 2 in. (50 mm) of the rock. The rate at which the nozzle cuts is primarily dependent on rock hardness. The most common measurement of this is the rock's compressive strength. The higher the compressive strength, the slower cutting of the rock will be. In carbonate rocks which often have compressive strengths over 10,000 psi (69 MPa), jetting with HCl or acetic acid dramatically improves the cutting rate. The time required to create a penetration can vary from 10 to 40 minutes depending on the cutting rate of the rock.

Applications for the LPT

- Reaches beyond formation damage and thick cement in almost all cases.

- Allows completion or stimulation near water or gas zones.

- Reduces drawdown and increases the effective wellbore radius to prevent coning.

- Improves rates and profiles of injection wells.

- Acid sensitive zones that require controlled stimulation.

- Carbonate zones that require controlled acid stimulation.

- Cut through scale , paraffin, or asphaltene deposits using acid and/or solvents.

THE SELECTIVE PUNCH JET TOOL - "SPJT"

Tool Description and How the Jet Cuts

The SPJT evolved as a result of development work on nozzles for the LPT. There are a number of applications for the use of liquid jet cutting that do not require 10 ft (3m) of penetration. A nozzle known as the "Leach and Walker" design which is commonly found in the liquid jetting industry, was found to have the ability to maintain a tight, focused, powerful liquid jet a substantial distance from the nozzle. The addition of friction reducing polymers add further to this ability.

Test results proved that this design allowed penetration over 3 ft (1 m) x .5 to 1.5 in. (13 to 38 mm) in diameter in some rocks. Even in hard carbonates, in jetting with HCl, deep penetration is possible. The tool's configuration is the same as for the LPT except that the 20 ft (6.1 m) lance section is removed, see Figure 2. In place of the lance section is an additional hydraulic line that supplies pressure and flow to the Leach and Walker nozzle that is built into the punch, see Figure 3. As the tool punches through the casing, the jet cuts the formation rock from fixed position and is able to continue cutting with an unusually long standoff from the rock face. The O.D. and size of hole in the casing for this tool are the same as for the LPT. The overall length of the tool ranges from 34 to 41 ft (10.4 to 12.5 m).

Test results show that the time involved in creating a tunnel with the SPJT is typically 1 to 5 minutes because the jet will reach its "stagnation point" relatively quickly. This allows for an overall faster and less expensive operation than the LPT requires. Because of the reduction in pumping time, depth of penetration, and tool requirements, the SPJT offers downhole users of liquid jet cutting technology a more economical method of completing or stimulating their production and injection wells.

Applications for the SPJT

- Provides large, clean holes to initiate hydraulic fracturing and reduce perforation friction.

- Improves heavy oil production, usually from unconsolidated sand where large entry holes aid in the flow of heavy sand laden oil.

- Allows for ultra-selective acidizing, with penetration in carbonates deeper than perforating.

- When invasion is known to be relatively thin, the SPJT jet can penetrate beyond it.

- In soft formations, where deep penetration is not required or is undesirable.

- Injectors that have near wellbore plugging resulting in reduced injection rate and increased injection pressure.

OPERATIONAL PROCEDURES FOR THE LPT AND SPJT

Additional Equipment Provided

- 200 to 300 HP pumping unit capable of delivering 10,000 psi (69 MPa) at 20 to 30 gpm (.08 to .12 m3/min.).

- Pumping cab and console to control, monitor, and record pump pressures and flow rates.

- High pressure pump lines rated for 10,000 psi (69 MPa) with a minimum burst of 34,000 psi (235 MPa).

- Pumping head rated for 15,000 psi (103 MPa) equipped with a velocity check valve, shut-in valve and bleed-off valve.

- High pressure workstring that is clean and inspected for 10,000 psi (69 MPa) service, equipped with a stabbing guide, set of pup joints and slip type elevators. Typically, 2-3/8" 5.95#/ft (60.3 mm, 8.9 kg/m) N-80 grade tubing with a premium connection is supplied. Minimum I.D. is 1.805 in. (45.8 mm).

Cycle of the LPT and SPJT

1. The tool string and workstring are run in the hole by an appropriate well servicing rig to the measured approximate depth for the first penetration point.

2. A 1-11/16" (42.9 mm) O.D. GR/CCL tool is run through the workstring to pick up a marker sub to correlate to a gamma ray log for depth control.

3. After the logging tool is retrieved from the well any depth adjustments are made and the appropriate setting weight is applied to the anchor.

4. Pumping pressure is increased to 6500 psi (45 MPa) where the control section shifts from the retract position to the extend position.

5. The punch extends through the well casing to provide access for the lance to the formation in the LPT and for the long standoff jet in the SPJT.

6. Pressure increases to 10,000 psi (69 MPa) and is held there for the respective time required for each tool. For the LPT, to allow the lance to extend to 10 ft (3 m) and for the SPJT, to reach its stagnation point.

7. Once the penetration is complete, pressure is reduced to 5000 psi (34.5 MPa) to allow the control section to reset to the retract position. The punch and lance are retracted into the tool in the LPT and the punch is retracted in the SPJT.

8. Pressure is bled off, the anchor is unset, the tool moved to the next penetration point and oriented as required and the anchor is reset.

9. The cycle is then repeated for the number of penetrations planned for the well.

REFERENCES

1. Peters, Alan D., "The Lance Formation Penetrator System." Presented at the 1990 Southwestern Petroleum Short Course, April 18-19, 1990.

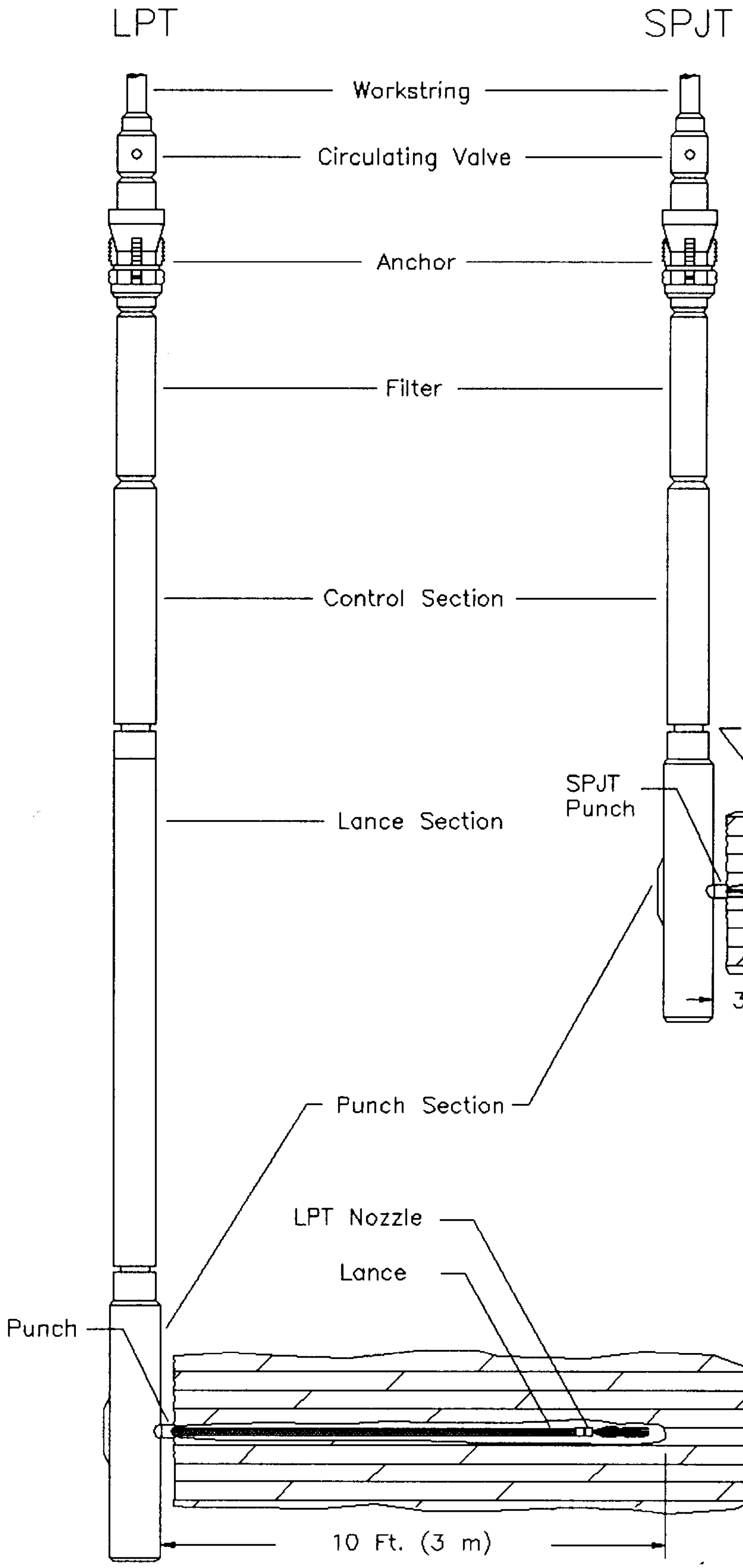
2. Labus, Thomas J. Fluid Jet Technology: Fundamentals and Applications. St. Louis, Mo.: Water Jet Technology Association Inc., 1991.

3. McLeod, Harry O., Jr., "The Effect of Perforating Conditions on Well Performance." J. Pet. Tech. (Jan. 1983) 31-39.

4. Maurer, William C. Advanced Drilling Techniques. Tulsa, Ok.: Petroleum Publishing Co., 1980.

5. Plummer, Charles C., and David McGeary. Physical Geology. Dubuque, Iowa: Wm. C. Brown Co., 1981.

6. Leach, S. J. and Walker, G. L., "Some Aspects of Rock Cutting by High Water Jets", Phil. Trans. Royal Soc. of London, A, 1100, 260, pg. 295-303, 1968.



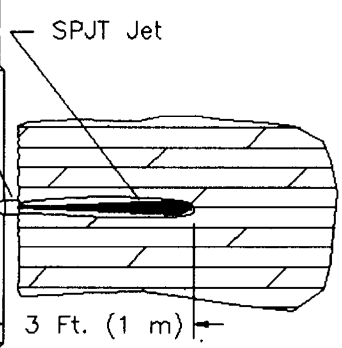
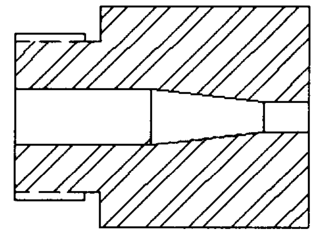


Figure 2

Figure 1



Leach and Walker nozzle in SPJT punch.

Figure 3