THE LANCE^{SM} FORMATION PENETRATOR SYSTEM

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ABSTRACT

This paper discusses the new, patented Penetrator Tool System which utilizes the principle of high pressure jet cutting to produce clean tunnels up to 10 ft. into formation rocks. Both the downhole system and the surface pumping equipment are described.

The theory of jet cutting of rocks is discussed and some empirical data are provided on penetrating hydrocarbon reservoir rocks. The effects of by-passing near wellbore formation damage and providing short, unobstructed drainage channels from the reservoir are reviewed.

Various applications of the Penetrator System in new well completions, recompletions, and workovers of older wells are outlined and case histories are presented illustrating where production or injection enhancement has been achieved.

INTRODUCTION

The Lance Formation Penetrator Tool utilizes the principle of liquid jet rock drilling as a formation completion and stimulation technique. Using a clean liquid media at high pressure, the objective in using the tool is to reach beyond near wellbore damage and extend up to 10 ft. radially into the formation.

The development of this system was begun by Penetrators, Inc. of Houston, Texas in 1984. Four U.S. patents and several equivalent foreign patents have been awarded, while six more are pending or are in application process. The current tool design is the sixth and final version of a line of prototypes which have been field tested for 3 1/2 years. Commercialization of the system was initiated at the end of 1988.

THE PENETRATOR SYSTEM

Downhole Tool System

The main tool consists of three sections which total 39.5 ft. in length and a maximum diameter of 3 3/4 in. or 4 1/2 in.. These sections are the control section, lance section, and punch section. See Figure 1 of the Appendix.

The control section is a pressure actuated, hydraulic directioning valve. At low pressure, it directs the hydraulics to retract the tool. At high pressure (greater than 6500 psi), it extends the tool.

The lance and punch sections are double acting, hydraulic piston assemblies. The lance section extends and retracts the lance, which is a 1/2 in. O.D. high pressure, armored, semi-rigid conduit with a nozzle in the forward end. The lance section also supplies the high pressure flow of liquid that is used for cutting of the formation rock. The punch section extends and retracts the steel punch that opens a 1 3/8 in. diameter hole in the casing. See Figure 2 of the Appendix for a hydraulic schematic of these sections.

The auxiliary sections above the main tool consist of a mechanical anchor to isolate tubing movement from the tool, a high pressure 60 micron filter to catch particles in the workstring, and a circulating valve to permit reverse circulation or to drain the tubing after the penetration job is completed.

Workstring

The typical workstring used in wells less than 11,000 ft. is 2 3/8 in. O.D. 5.95 lb/ft, N-80 or L-80 Grade tubing with PH-6 Hydril connections. This heavy wall pipe is required due to the 10,000 psi surface injection pressure.

Cleanliness of the workstring is important to prevent scale and rust from dislodging from the tubing wall and plugging the tool or being pumped out into the productive zone.

Pumping System

A maximum surface pressure of 10,000 psi at a rate of 20 gpm is supplied by a triplex or quintiplex pump. A centrifugal charge pump supplies suction pressure to the triplex after passing the completion fluid through a 10 micron filter unit.

Action of the Tool

A complete cycle of the tool occurs in the following sequence. See Figure 3 of the Appendix which is a multi-channel recorder plot of pressure and volume variations during the cycle.

1. With the anchor set, pump pressure in the workstring and tool builds from 0 to 6500 psi. The control section then shifts to the "extend" position.

2. The steel punch and the lance begin extension simultaneously.

3. As the punch pierces the casing and completes its cycle, the jet from the lance begins washing out cement and cutting a pilot hole in the formation.

4. With the hole in the casing made by the punch, the lance extends out into the formation with the jet cutting a penetration ahead of the lance. Pumping is maintained at 10,000 psi and 16 to 20 gpm until the lance has time

to reach a full extension of 10 ft.

5. Pressure is reduced to 4000 psi, the control section resets to the "retract" position and the punch and lance are pumped back into the tool.

6. Pressure is reduced to zero psi and the tool is ready to be moved to the next penetration point.

7. This cycle is repeated for each hole that is to be made.

JET CUTTING OF FORMATION ROCKS

Jet cutting of formation rocks is not a principle which is new to the oilfield industry. Jet nozzles were introduced into rolling cutter oilfield rock bits in the 1950's and today modern rock bits, both rolling cutter and drag (PDC) types, have extended nozzles for jet assisted rock cutting. During the 1960's and 1970's Exxon and Gulf oil companies experimented on a large scale with high-pressure jet drilling both in the laboratory and in the field. Their experiments included the use of entrained abrasives (grit) in the jet stream. Since the 1950's, major oilfield pumping service companies have offered jet abrasive devices for cutting oil and gas well casings.

In general industry, high pressure water jet cutting with pressures up to 50,000 to 60,000 psi is employed to cut textiles, wood, and steel plate. In aerospace, jet cutting is used to cut mounting holes in the extremely tough and thick walls of rocket motor cannisters made of filament wound graphite fiber. Water blasting, with pressures up to 20,000 psi, is widely used now for industrial cleaning. The Penetrator Tool is an adaptation of high pressure jet cutting into a downhole tool where the system has an encapsulated, extendable lance.

Reservoir Rock Characteristics

Jet cutting of reservoir rocks is accomplished by dislodging grains or particles of rock from the matrix or cementation with a high pressure, high velocity liquid jet. Pumping at 10,000 psi at 20 gpm, using 2% KCL water, translates to a jet velocity of 1200 ft/sec.

Using the equations:

$$\text{Impact Force} = 1/2\ MV^2$$

$$V = \text{Velocity - ft/sec}$$

$$V = c\sqrt{2gH} \text{ or } V = 35.2\sqrt{\frac{P}{\rho}}$$

$$P = \text{Pressure drop across nozzle - psi}$$

$$\rho = \text{Fluid density - lbs/gal}$$

it can be seen that with an increase in pressure and/or a decrease in fluid density, an increase in velocity occurs. This velocity increase greatly increases the impact force on the rock surface.

The pressure required to cut reservoir rock is a function of the compressive and tensile strengths of the rock. This is termed the "threshold pressure". Compressive and tensile strengths vary widely within rock types as seen by the following table:

Rock Type	Compressive Strength (psi)	Tensile Strength (psi)	Threshold Pressure (psi)
Sandstone	2800 - 8400	56 - 168	2000 - 4200
Limestone	2240 - 7840	168 - 336	3600 - 6000
Dolomite	4480 - 16,500	168 - 504	4200 - 7300
Granite	5600 - 25,600	168 - 280	6200 - 9800

Threshold pressure of a particular rock will also depend on chemical composition, porosity, permeability, degree of natural fracturing, elasticity, and overburden pressure.

How the Jet Cuts

In the well the jet stream is submerged under the hydrostatic head (pressure) of the fluid in the well annulus being used to keep the well under control. Within the tool this annular hydrostatic pressure is balanced with the tubing hydrostatic pressure when the tool is not activated. Injection pressure across the nozzle is added to the tubing hydrostatic pressure. As long as the stand-off distance from the nozzle tip to the rock face is maintained at not more than 6 to 8 inches, the lance will drill. For this reason, the lance sub-system is designed so that a forward thrust of 900 lbs. is exerted axially along the lance at 10,000 psi injection pressure. This is intended to ensure minimum stand-off. This allows for quick and efficient cutting of the rock. The rate of cutting of each rock type relates back to the threshold pressure of the rock.

EFFECTS ON NEAR WELLBORE FORMATION DAMAGE

One of the primary applications of the Penetrator System has been to reach beyond formation damage around the wellbore. Elements of formation damage may include:

1. Drilling mud filtrate invasion
2. Cement invasion
3. Fines migraton
4. Chemical incompatabilities which could cause clay swelling or water blocks.
5. Perforation debris and compaction.

The common term to represent the effects of formation damage on the production potential of a well is the "skin" factor. In most formations where some type of damage has occured, it is within 2 to 4 ft. from the wellbore. This area is commonly called the damaged or "invaded" zone. Perforating techniques presently in use will not penetrate beyond the invaded zone. The total pressure drop across the invaded zone and perforation compaction can significantly reduce flowing bottom hole pressure and production rate.

At 10 ft. in length, a penetration, in most cases, will reach far beyond the invaded zone and will not create compaction on the reservoir rock like that of a perforation. In addition, the larger length and diameter (9/16 in. to 1 in.) of a penetration tunnel provides more surface area than a perforation for communication between the wellbore and the reservoir. This will result in a reduction of pressure drop across the completed interval and an increase in production. See Figure 4 of the Appendix for a wellbore diagram.

APPLICATIONS

The following is a description of various well conditions in new completions, recompletions, and workovers where the system has been used or considered:

1. Wells with high positive skin (formation damage) as defined from well test analysis and other methods.

2. Wells with a thick cement sheath due to a washout or squeeze work that cannot be penetrated by perforating guns.

3. Zones that usually would be candidates for hydraulic fracturing, but do not have containing barriers to prevent the vertical growth of fractures into undesireable neighboring zones.

4. Zones that tend to cone water or gas by producing close to fluid contacts. By enlarging the effective wellbore, the drawdown near the well will be reduced.

5. Injection wells that have difficulty establishing acceptable injection rates or have an inconsistent injectivity profile.

6. Zones that are known to be acid sensitive which can be further damaged by the injection of certain treating fluids.

7. Water or chemical disposal wells that require excessive pressure to take fluid at economical rates.

8. Wells with secondary damage due to scale, paraffin, chlorides, etc..

9. Zones of low permeability (1md. to 25md.) that could produce at economical rates with a skin of zero or less by using the Penetrator tool.

10. Wells with substantial drawdown that have normal shut-in pressures but decrease significantly when produced.

Other Applications

The following describes an application of jet cutting using an extended version of the Penetrator System which would extend out 100 ft. from the wellbore. This project is currently unfunded and inactive.

1. With the extended version of the system, it can be used in the "drainhole" concept or other applications of horizontal drilling.

2. In reservoirs with micro-darcy permeability or where vertical fracture systems must be crossed, the extended version could reach out in several different directions.

CASE HISTORIES

The following are several different applications where the Penetrator System was used. Conditions of the well and results are given.

Case 1

Location: Pecos Co., Tx. Formation: San Andres
Completion Fluid: 7 1/2% HCl Depth: Below 1170 ft.
No. of Penetrations: 6

Application: This field had been repressured by gas injection to create a strong gas cap drive. With the oil pay shrinking, gas cap coning had become prevalent. When the GOR reached 10,000 cf/bbl, wells were "pancake" cement squeezed in an attempt to eliminate the coning. This technique had impaired the oil zone and the well was shut in.

Results: Before penetrating, the well tested 46 BOPD, 3 BWPD, and a GOR of 10,000+ cf/bbl. After penetrating, the well tested 128 BOPD, 3 BWPD, and a GOR of 600 cf/bbl. After two years, the well tested 50 BOPD, 4 BWPD and a GOR of 2500 cf/bbl and was still economically producible.

Case 2

Location: Stephens Co., Tx. Formation: Lake Sand
Completion Fluid: 4% KCl Depth: Below 3644 ft.
No. of Penetrations: 13

Application: Previous attempts to complete this thin inter-bedded gas sand with closely associated water usually resulted in approximately 90 Mcf/day with 100 BWPD.

Results: After penetrating this new well completion, the well flowed 400+ Mcf/day on a 40/64 choke with a trace of water. The allowable was set at 180 Mcf/day and continued to flow with very little water production.

Case 3

Location: Austin Co., Tx.
Completion Fluid: 4% KCl
No. of Penetrations: 15

Formation: Lower Wilcox
Depth: Below 10,897 ft.

Application: This well was described as very sensitive to fresh water and acid. This well had been damaged from acidizing by a previous owner and was shut in with no fluid entry during testing.

Results: The well was swabbed in and produced gas intermittently between periods of "loading up" while returning the completion fluid. After a small CO_2 fracture treatment, the well cleaned up and is flowing 500 to 700 Mcf/day of dry gas.

Case 4

Location: Brazoria Co., Tx.
Completion Fluid: 10 lb. Brine
No. of Penetrations: 24

Formation: Limestone
Depth: Below 6156 ft.

Application: This industrial waste water disposal well was originally perforated and acidized with unsatisfactory injection rates resulting. Regulatory agencies would not allow any fracture treatment or additional explosive perforating due to potential damage to fiberglass casing, cement job, and barrier zones above and below the injection zone.

Results:	Injection Rate	Injection Pressure
Before Penetration Job:	32 gpm	1100 psi
After Penetration Job:	200 gpm	400 psi

Case 5

Location: Gaines Co., Tx.
Completion Fluid: 2% KCl
No. of Penetrations: 16

Formation: San Andres
Depth: Below 5411 ft.

Application: The first attempt on this new well completion consisted of:

1. Perforating 2 shots/ft, resulting in no fluid entry.

2. Acidized with 15% HCl. Pressured up to 3000 psi and could not break down the formation. Normal breakdown pressure is 1800 to 2400 psi. The result from the acid job was no fluid entry.

Results: After the penetration job was completed, 500 gal. of 15% HCl was spotted and taken by the formation without any pump pressure build-up. The resulting production was 45 BOPD and 115 BWPD. After putting the well on pump, the water reduced to 50 BWPD.

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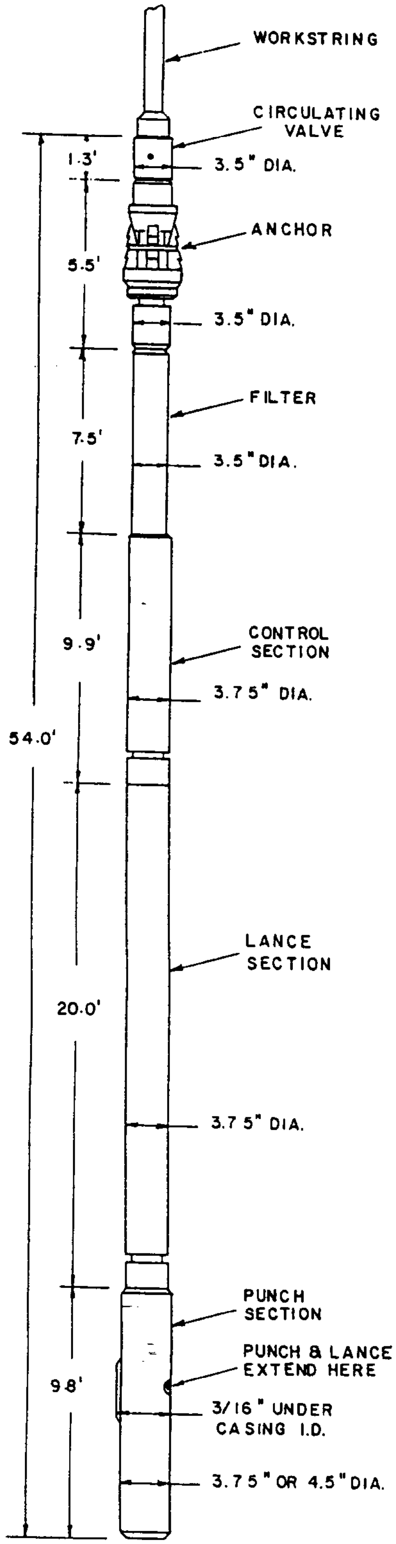


Figure 1

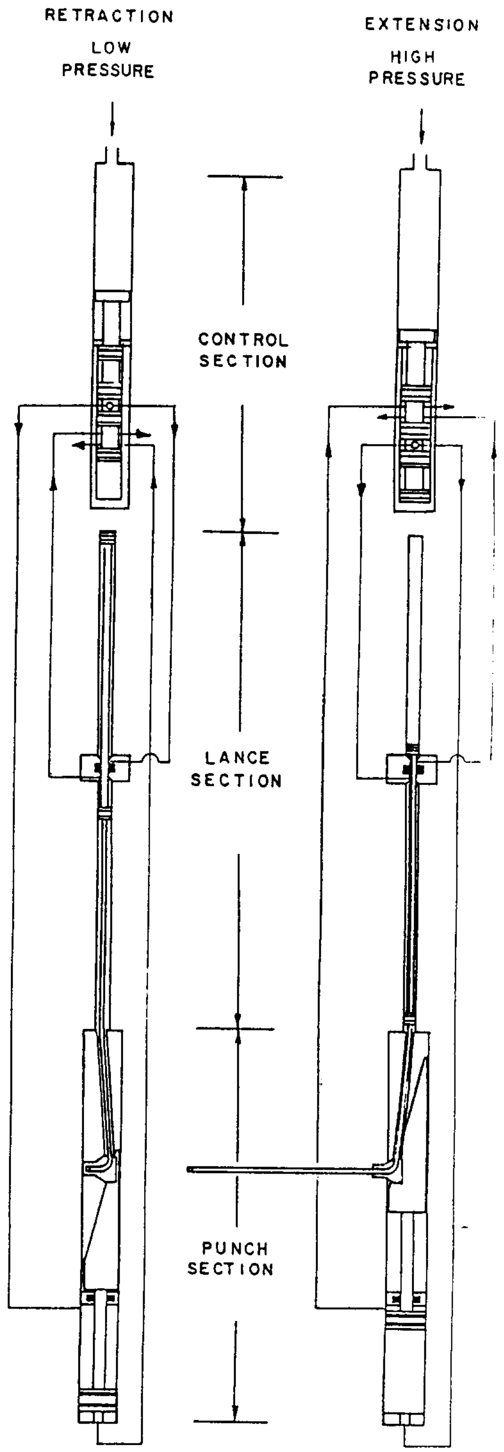
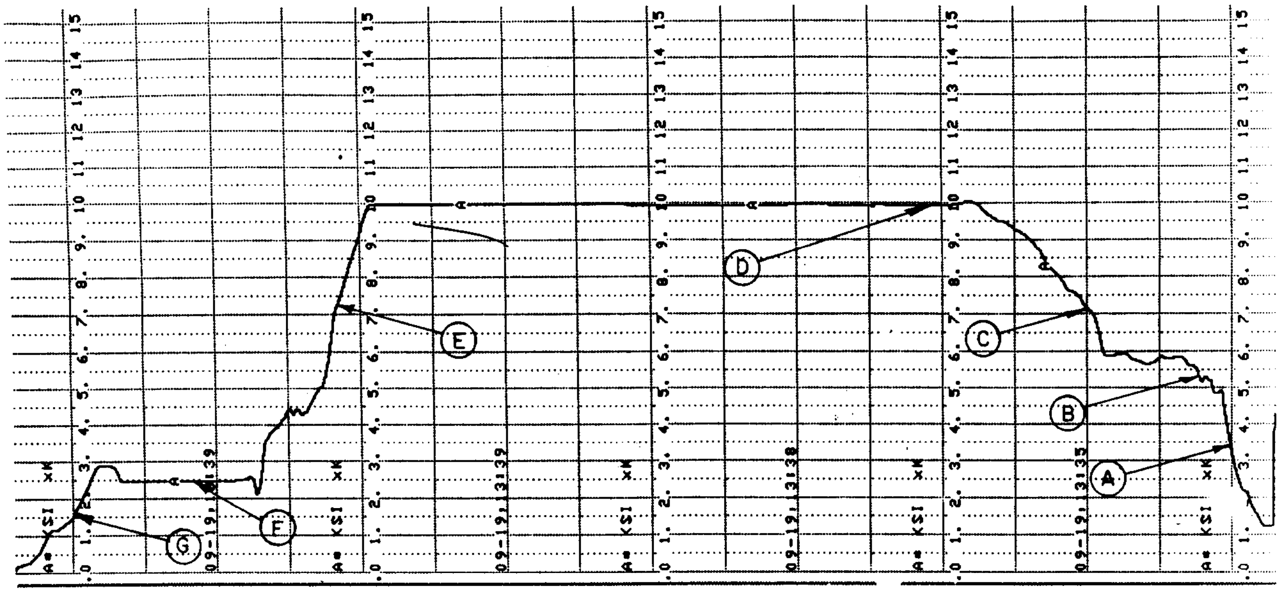


Figure 2



A- Pressurizing the workstring.
B- Control Section shifts to the "extend" position.
C - Punch and Lance begin extension as pressure increaces to 10,000 psi.
D- Pressure remains at 10,000 psi as the Lance cuts a penetration.
E - Pressure is reduced to reset the tool to the "retract" position.
F- The Punch and Lance are pumped back into the tool.
G - Pressure is reduced to zero. Cycle is complete.

Figure 3

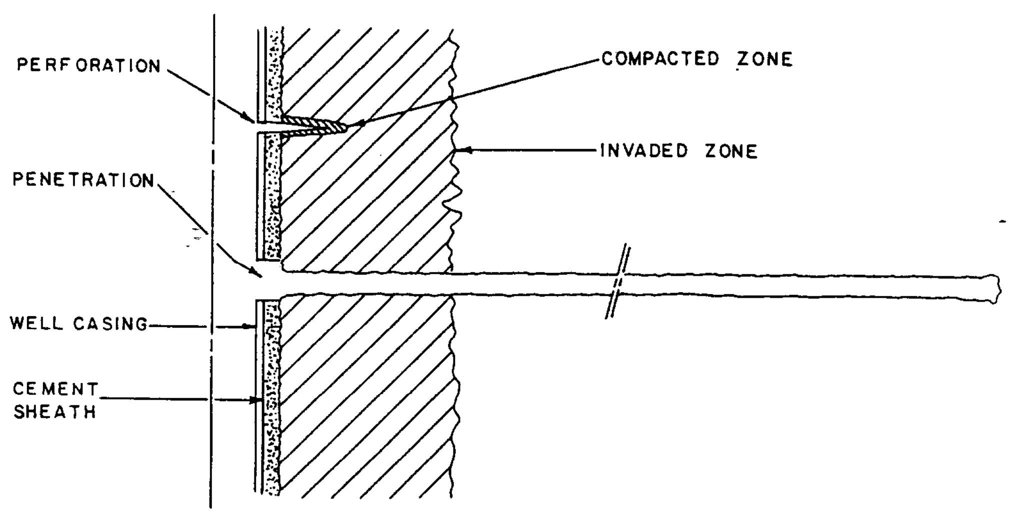


Figure 4