A NEW SELF-DECENTRALIZING HYDRA-JET TOOL

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INTRODUCTION

The use of a fluid containing an abrasive for perforating casing and cleaning open hole has been an established technique for many years. Generally, the jetting tool is installed on tubing along with a collar locator, tubing hold-down, centralizer, and in some instances an anchor-swivel. The tool is then lowered to the desired perforating or jetting depth to be cleaned.

Perforating or jetting operations are initiated by pumping the abrasive fluid into the tubing conductor, then to the jet body, and out the jet nozzles at relatively high differential pressure on to the surface or surfaces to be cut or penetrated. Conversion of the pressure into kinetic energy imparts high velocity to the abrasive particles, which upon impact with the formation face or casing wall will erode the material in an organized pattern.

A prime deterrent to effective hydraulic perforating an openhole section in an old well is the extended stand-off distance at which the perforating or jetting operation must be performed. This condition is particularly aggravated and critical in "shot" holes and openhole sections which have been previously acidized or fractured and have since become scaled or plugged.

The purpose of this paper is to present a self-decentralizing hydraulic perforating tool which produces unbalanced forces and which, when coupled with a flexible fluid conductor, will provide a novel combination resulting in near zero stand-off hydraulic perforating conditions for improved effectiveness in perforating or penetrating a formation face in open hole. A sketch and general operating procedure plus some equations involved in development and several pertinent to its effectiveness for penetrating rock or scale are set forth. In general, this discussion is presented along operational lines and is substantiated by test target results, pictures, and after treatment responses. These results present concrete evidence, confirmed by representatives of various oil companies in West Texas and Southeast New Mexico that the successful development of the tool for perforating or penetrating formations in open hole or "shot" hole is an accomplished fact, and that this process can be relied on to penetrate rock or scale.

BACKGROUND INFORMATION

Hydraulic Equations

The velocity, V, (in ft/sec) of a water jet (neglecting friction) is:

$$V = 12.2 \sqrt{p} \qquad (1)$$

And the power output, P, (in HP) of a hydraulic jet (water jet) can be found from:

$$P = 0.0223\, nap^{3/2} \qquad (2)$$

Where:

n = Number of orifices
a = Area of orifice, in.^{2}, and
p = Pressure drop across orifices, psi

The flow rate, Q, (in gal./min) through a nozzle is given by:

$$Q = 69D^2 \sqrt{\frac{p}{8.33}} \qquad (3)$$

Where:

D = Diameter of nozzle, in., and the constant 69 includes a discharge coefficient of 0.80.

The reaction force, F, (in lbs) of the nozzle is:

$$F = 1.5\, D^2 p \qquad (4)$$

Rock Penetration

Leach and Walker[1] observed in their work that there exists a critical pressure below which significant penetration of a rock does not take place and that this pressure increases with harder rock. This threshold pressure was also noted by Maurer et al[2] in high-pressure jet drilling of hard rock. As the pressure was increased above this value, the drilling rate increased very rapidly. Many water jets will effectively penetrate or drill weak materials such as coal, some mineral deposits or weak sandstones, but will not drill hard rocks such as granite or basalt. Abrasives such as sand or steel shot have been used in erosion bits operating below threshold pressure; however, these abrasive jets penetrate or remove rock by an inefficient erosion mechanism resulting in low drilling rates. High-pressure water jets operating above the threshold pressure shatter rock into pieces. This is an efficient penetrating or rock removal mechanism.

Brooks and Summers[3] have produced graphs in which it can be seen that within the range chosen the penetration of the jet varies directly with the pressure, and inversely with the stand-off distance. Most of the penetration was effected in the first few seconds of the jet action, and was considered to be significant. Farmer and Attewell[4] and other investigators have shown that the effective pressure of the jet is very much reduced with increase in hole depth, but the mechanism of this is not fully explained. Clark et al[5] noted in their work that Russian investigators obtained maximum slot depths with minimum stand-off and for rock breakage, stand-off should be zero.

Since the self-decentralizing hydra-jet tool embodies functional design characteristics and sufficient strength for operating conditions predisposed to effective hydraulic perforation of open hole, the following advantages and possible uses of the tool become evident:

1. Provides zero or near zero stand-off jetting conditions
2. Obtains much greater depth of penetration than previous conventional jetting tools
3. Permits more effective removal of scale or gunk deposits from open-hole formations to improve water injection
4. Provides a better approach to stimulating an oil zone or stringer which may lie near a potentially water-bearing zone
5. Provides a means of penetrating or removing a gypsum or barium-strontium sulfate deposit from open-hole and shot-hole sections
6. Provides oil producer with a more efficient and effective means of enlarging a particular zone or zones in open hole and thus improves the probability of fracturing a plurality of zones in subsequent multiple stage fracturing operations
7. Can effectively gain entry and stimulate damaged or tight sections which could not be stimulated with acid and diverting materials employing radioactive interface techniques
8. Enables operator to be more selective or discreet in removing offending gyp scale from hydrocarbon producing sections only. Not so with solvents, convertors, or disintegrators
9. Provides a more effective method of stimulating new hole made below old hole or shot hole
10. Is more effective in removing scale and gunk from open-hole sections than previous jetting tools
11. Is tremendously more efficient in transmitting horsepower input or energy impact to the formation face than "conventional" hydraulic jetting tools since stand-off distance is greatly reduced.

EXPERIMENTAL PROCEDURE AND RESULTS

Studies and approaches to experimental design of the tools and equipment were very limited. The concept evolved from phenomena exhibited by jet airplanes, vertical take-off aircraft, rockets, line moles, and other mechanisms or devices associated with dynamic thrust or reactionary forces. Ultra-high-pressure-range steel-braided flexible hoses provided the solution to flexibility; and polished jet nozzles and experience gained in conventional hydraulic jetting provided the necessary equipment and know-how. Thus, the idea was conceived, and with the exception of nozzle sizes, arrangements, and placement angles the self-decentralizing hydra-jet tool as we know it today was developed. Figure 1 reveals an artist's concept of the functional tool. Figures 2 and 3 show the two types of tools in field service today.

Experimental surface tests were performed using service company pumping equipment, open storage tanks, and cement targets. Test targets were prepared using Class "H" and gypsum cements. Combination-type targets in which the inside cylinder wall of the Class "H" cement target was covered with a sheath of gypsum cement from 2-1/4 in. to 2-3/4 in. were also made. Corrogated cardboard cylinders and 55-gal. drums were used as molds. Both solid and cylinder-type targets were poured and cured from 13-16 months at atmospheric conditions. Target compressive strengths ranged from 6000-8000 psi.

Prior to jetting the targets, a chemically resistant paint was applied to the target mass and permitted to dry. The latter was covered with 1/8-3/4 in. roofing tar. This approach was taken in an attempt to simulate tenacious downhole wellbore mineral and hydrocarbon deposits, and to retard chemical attack on the target surfaces. Figure 4 is a photo of a solid target as used in tests 1 through 3.3. Figure 5 is a photo of a cylindrical target as used in tests 4 through 10. The targets were then individually tested by placing them in the test tanks and positioning the jet head 3-5 in. from the target face or inside cylinder wall. The jet head was suspended on a 2-ft length of ultra-high-

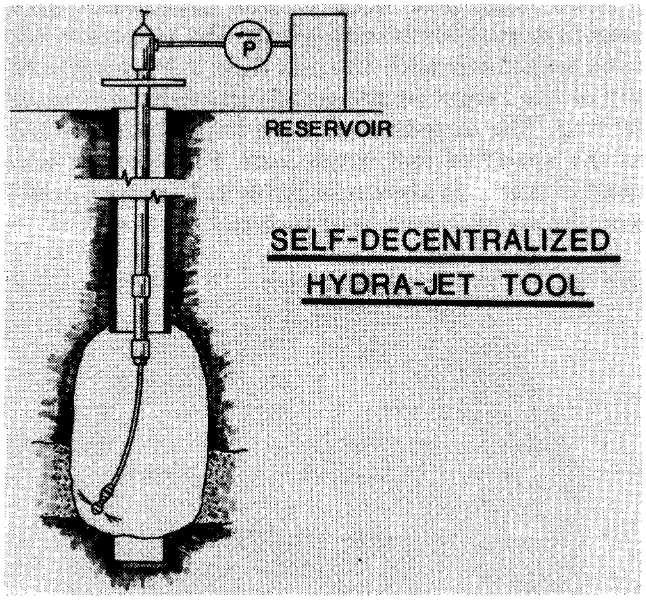


FIG. 1—FUNCTIONAL SELF-DECENTRALIZED HYDRA-JET TOOL

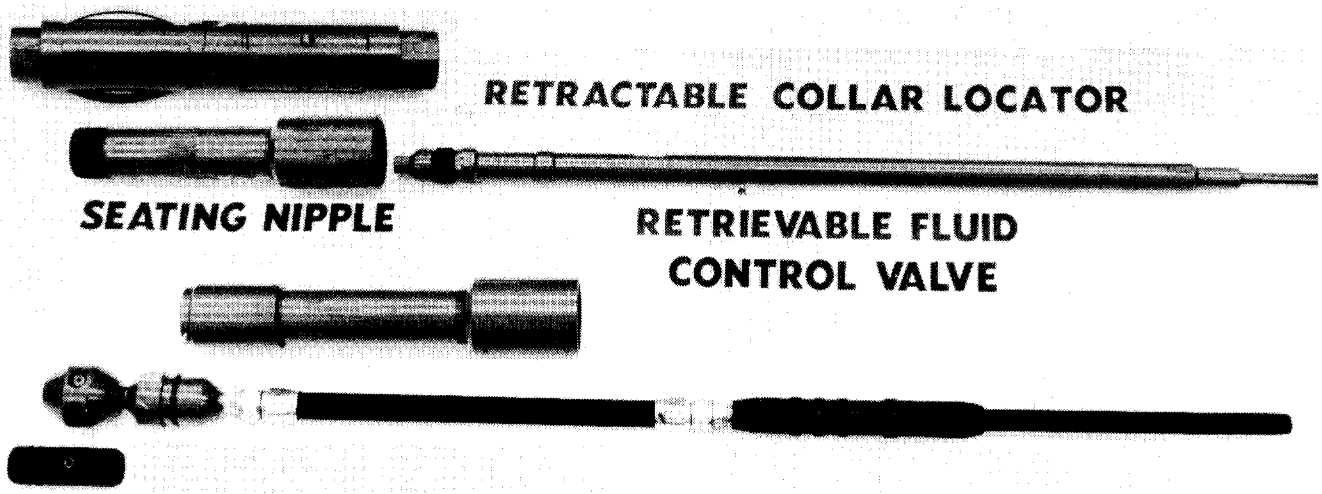


FIG. 2—RETRIEVABLE-ON-TUBING SELF-DECENTRALIZED HYDRA-JET TOOL AND AUXILIARY TOOLS

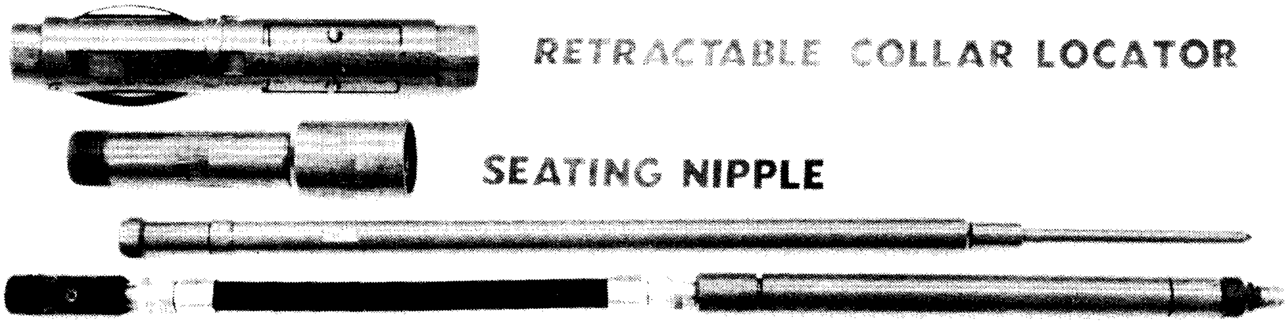


FIG. 3—RETRIEVABLE-THROUGH-TUBING SELF-DECENTRALIZED HYDRA-JET TOOL AND AUXILIARY TOOLS

pressure steel braided hose and the upper end was screwed into a standing valve equipped with a strainer. The standing valve was placed in a seating nipple, and the seating nipple made up into the end of the pump discharge line. Twenty-eight feet of 2-in. discharge line was used. The end of the discharge line attached to the hose was suspended and secured to a fork lift truck which was adapted and modified for positioning and moving the jet head while testing.

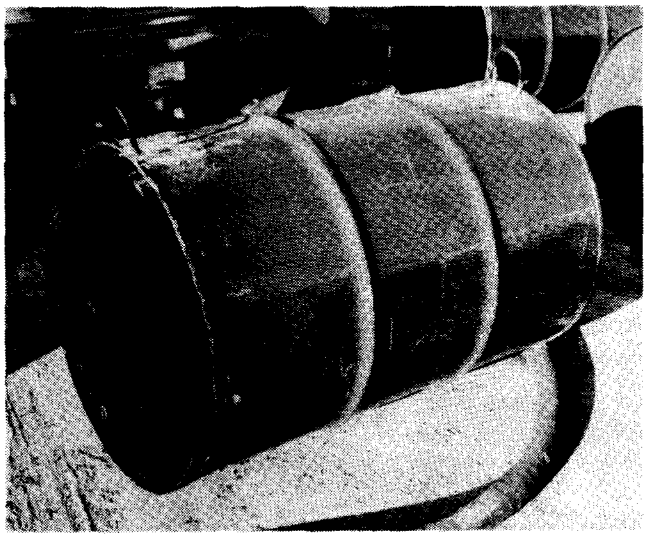


FIG. 4—SOLID TARGET OF TYPE USED IN TESTS NOS. 1 THROUGH 3.3

FIG. 5—CYLINDRICAL TARGET OF TYPE USED IN TESTS NOS. 4 THROUGH 10

After the test target and jet head were satisfactorily positioned within the test tank, the tank was filled with the test fluid 2-3 ft above the top of the target to prevent fluid cavitation while testing. The targets were then immediately jetted at the specified test conditions. Fresh water was used in test 1 as shown in Table 1. Figures 6 and 7 are photos of target used in test 1.

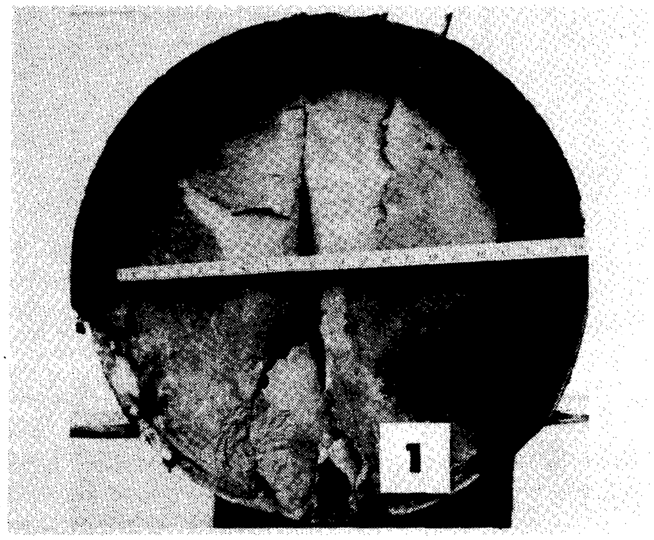


FIG. 6—TEST TARGET JETTED WITH FRESH WATER IN TEST NO. 1

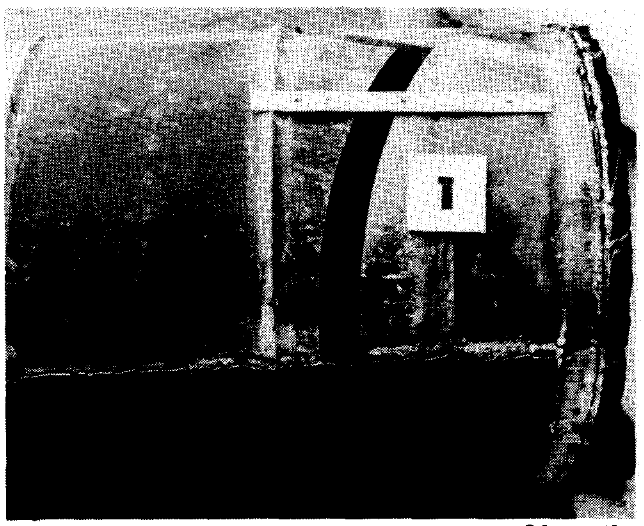


FIG. 7—SIDE VIEW OF TARGET SHOWN IN FIG. 6 AFTER SUPPORTING MOLD WAS PARTIALLY REMOVED

In the remainder of tests, HCl concentrations of 15 and 28% were used. All fluids contained 1 gal. acid inhibitor, 1 gal. surfactant, and 5 lb friction reducer per 1000 gal. The friction reducer and surfactant were used primarily because other investigators had found that they improved the jet stream performance and resulted in greater penetration depth. The superior performance was attributed to improved fluid cohesion, higher fluid velocity, resulting in higher impact energy at the target face and subsequently greater penetration rate and depth. The acid inhibitor was added to the water as a control in maintaining consistency and uniformity in test procedure.

All tests were conducted at pressures in excess of 5000 psi with the exception of tests 6 and 6.1, which were conducted at 2500-2700 psi. Flow rates at the test pressure conditions were dictated by the number of nozzles in the jet heads used, but were usually within the range of 48-105 GPM.

The tests were conducted at and limited to 5000 psi nozzle pressure differential to determine the following:

1. If a simulated wellbore of acid-insoluble mineral and/or hydrocarbon deposit could be penetrated or removed
2. If the jet stream would penetrate the material
3. Which jet fluid appeared to be superior for removal of materials
4. Which jet head appeared to be superior in the removal of materials
5. The influence of stand-off on the penetration or removal of the tar and acid-resistant paint and target mass.

The test conditions and results are reported in Table 1. Generally, a review of the findings in Table 1 would point out that:

1. The jet nozzle or nozzles at zero stand-off were drastically more effective in penetrating the rock face than were the opposite nozzles functioning at greater stand-off distances.
2. No fractures were initiated in the target faces in front of the opposite nozzles.
3. The zero stand-off nozzle did penetrate or remove the tar and paint deposit more effectively. (See Table 1, tests 4 through 10).
4. Acid did not appear to penetrate (fracture) the target any deeper than water. Note: Not reported in Table 1 was the solution effect of the fluids since the gypsum cement is only slightly soluble in any of the fluids used; however, the fractures, targets, and target fracture detrital of the cement targets or combination targets were drastically eroded or pitted by the acid. Compare Figs. 6 and 8. Figure 6 is a photo of target after jetting with water. Figure 8 is a photo of an identical target jetted with the same nozzle at identical pressure using 15% HCl solution, but for a much shorter time period. Note the greater erosion and pitting in Fig. 8.

TABLE 1—TEST CONDITIONS AND RESULTS
PRESSURE RANGE 5000 - 5300 PSI
TARGETS (CEMENT; GYPSUM CEMENT; CEMENT AND GYPSUM CEMENT)

TEST NO.	NUMBER OF NOZZLES @ TARGET FACE	OPPOSITE FACE	JET TIME, SEC	TOTAL VOL. GALS.	MAX. PENETRATION, IN. TARGET FACE	OPPOSITE FACE	TAR & PAINT REMOVED TARGET FACE	OPPOSITE FACE
1 (1)(S)	1	2	463	378	21(V)(R)	-	Y	-
2 (2)(S)	1	2	247	202	14(V)(R)	-	Y	-
3 (2)(S)	5	4	T	T	13(V)(R)	-	Y	-
3.1(2)(S)	5	4	76	126	21(V)(R)	-	-	-
3.2(2)(S)	5(G)	4	77	126	4½	-	Y	-
3.3(2)(S)	5(G)	4	147	252	6½	-	-	-
4 (2)(C)	5	4	83	126	5 3/4*(V)(H)	0	Y	N
5 (2)(C)	5(GOC)	4	73	127	4(V)(H)	0	Y	Y
5.1(2)(C)	5(GOC)	4	150	250	4½(V)(H)	0	Y	Y
6 (2)(C)**	1(G)	2	107	126	3/4	1/8	Y	Y
6.1(2)(C)**	1(G)	2	110	126	4	5/16	Y	Y
7 (3)(C)	5(M)	4	89	98	5½*(R)	3/16	Y	Y
8 (3)(C)	5(M)	4	117½	176	3½(R)	½(P)	Y	N
9 (3)(C)	5(M)(GOC)	4	125	198	1½	0	Y	Y
10 (3)(C)	1(M)(GOC)	2	97	75	3	0	Y	Y

(1) - Fresh Water
(2) - 15% HCl
(3) - 28% HCl
S - Solid Target
C - Cylinder Target
G - Gypsum Cement
GOC - Gypsum Cement Over Cement
* - Limited by Target Size
V - Vertical Fracture

H - Horizontal Fracture
R - Radial Fracture
T - Test Terminated
M - Moving Jet Head Vertically
Y - Yes
N - No
P - Pit
- Not exposed to nozzle impact or absent
** - 2500 - 2700 psi; tool centralized; 3/16" nozzles; but target moved to zero stand-off

Figures 9 and 10 corroborate the observations made in Figs. 6 and 8. Figure 9 is another view of the target depicted in Fig. 6. Figure 10 is a similar view of the target shown in Fig. 8.

5. The 9-nozzle and 3-nozzle jet heads appeared to be about equally effective in maximum fracture penetration.
6. The jet stream of the zero stand-off nozzle penetrated the tar, paint, and all the cementitious materials tested in every case.

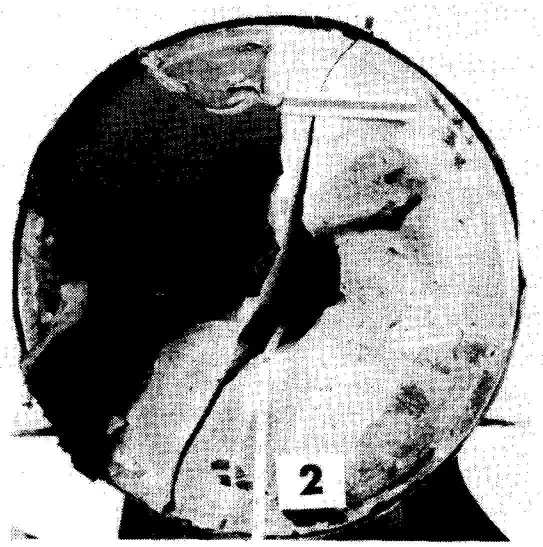


FIG. 8—TARGET JETTED WITH ACID SOLUTION

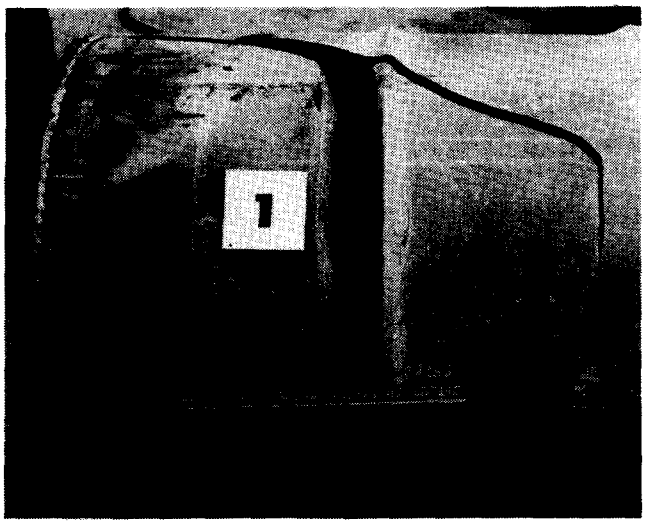


FIG. 9—SIDE VIEW OF TARGET JETTED WITH WATER IN TEST NO. 1

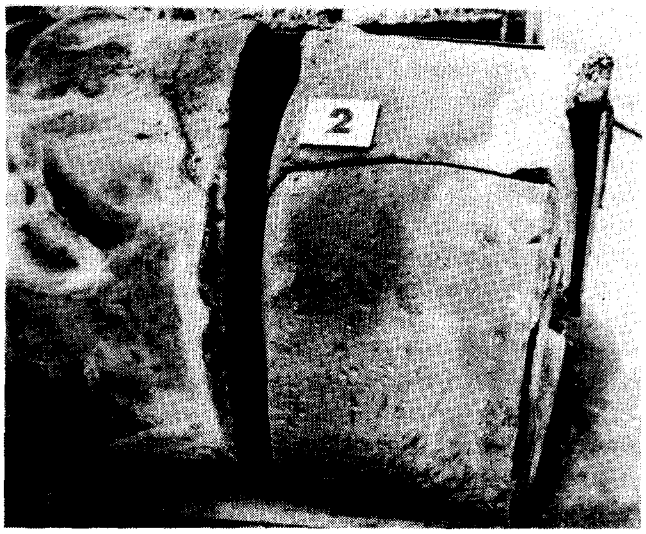


FIG. 10—SIDE VIEW OF TARGET JETTED WITH ACID SOLUTION

FIELD TESTS AND RESULTS

Background Information

Table 2 is a summary of some field jobs performed with the decentralized hydra-jet tool in 1973-1974. All the wells jetted were open-hole completions and ranged in age from 17 to 44 years. A number were temporarily abandoned and one well had been abandoned seven years. Generally, they were all strippers and all were jetted at the maximum permissible pressure. Most of the wells had low fluid levels and would not circulate. All but one well had been stimulated and a number of them had been shot. They were usually located in a field flood program, and 40-50% of the wells exhibited scale deposits. Others were suspected to have gypsum deposits; however, this was not

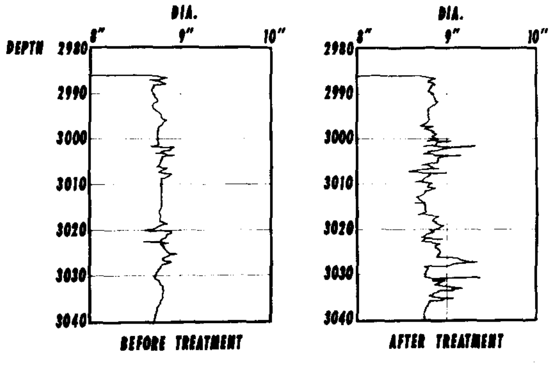
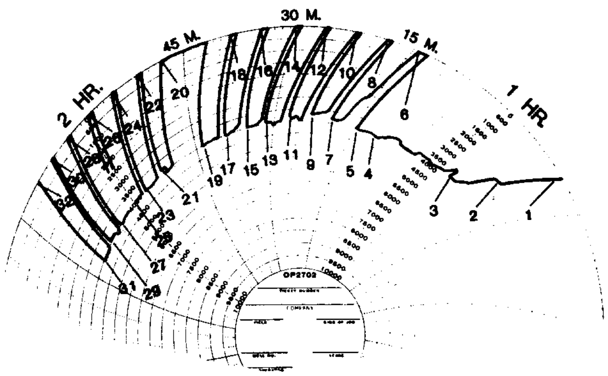


FIG. 11—CALIPER LOG BEFORE AND AFTER TREATMENT



TYPICAL CHART FROM DECENTRALIZED HYDRA-JET JOB

FIG. 12—TYPICAL PRESSURE CHART FROM ACTUAL DECENTRALIZED HYDRA-JET JOB

definitely confirmed. Nitrogen was employed in treating three of the wells. Two wells were calipered before and after treatment, and the calipers from one of the wells surveyed are set forth in Fig. 11. A well treating pressure chart taken from one job is shown in Fig. 12. The average total flow was increased to 255% of the flow prior to treatment of the 17 wells presented in Table 2.

Usually the following general workover procedure was pursued for treating wells using the "retrievable on tubing" self-decentralized hydra-jet tool:

1. Pull rods and pump.
2. Lower tubing and check total depth. Clean hole of debris and strap out, if necessary.
3. Run self-decentralized hydra-jet tool (and fluid control valve if needed) on "clean" 2-3/8 or 2-7/8 in. tubing (tested to 5000 - 7000 psi) to total depth. Raise tool (hose length) above lowest stringer or depth to be jetted.
4. Load tubing and very slowly pressure up to shear adapter-retaining pins, permitting jet hose to move out of tubing, thus positioning jetting tool opposite stringer or zone to be jetted.
5. Bring rate and pressure up to 1.0-3.5 BPM to obtain 5000-6000 psi through jetting nozzles.
6. Jet stringers or zones as desired.
7. Retrieve fluid control valve on sand line and pull tubing with tool.
8. Run bailer, check for fill-up, and place well on production.
   NOTE: Actual jetting time ranges from 1/2 to 2-1/2 hours depending upon treating rate, volume of acid used, and method of jetting well.

TABLE 2—SUMMARY OF SOME 1973 - 1974 SELF-DECENTRALIZED HYDRA-JET TREATMENTS

NO.	COUNTY	FIELD	FORMATION	ACID GALS.	PRODUCTION, BBLS/DAY BEFORE OIL/WTR.		PRODUCTION, BBLS/DAY AFTER OIL/WTR.		COMPLETION DATE, YEAR
1	Lea	Grayburg-Jackson	Grayburg-San Andres	7,000	6	4	66	12	1958
2	Andrews	Midland Farms	San Andres	3,400	0	239	18	212	1951
3	Andrews	Emma Cowden	San Andres	4,000	18	82	33	295	1941
4	Andrews	Midland Farms	San Andres	3,000	5	12	52	117	1952
5	Andrews	Emma Cowden	San Andres	4,000	62	35	133	82	1942
6	Andrews	Midland Farms	Grayburg	1,000	3	55	18	216	1949
7	Andrews	Midland Farms	Grayburg-San Andres	1,800	25	26	39	52	1951
8	Andrews	Midland Farms	Grayburg	4,800	2	0	5	256	1951
9	Andrews	N. Emma Cowden	San Andres	4,000	50	60	174	239	1941
10	Andrews	Mabee	San Andres	5,500	6	0	37	14	1945
11	Lea	Grayburg Jackson	San Andres	9,660	6	4	14	10	1931
12	Andrews	Emma Cowden	San Andres	4,000	10	70	53	80	1938
13	Andrews	Mabee	San Andres	3,800	63	0	102	2	1946
14	Andrews	Emma Cowden	San Andres	4,000	100	50	125	80	1940
15	Scurry	Kelly Snyder	Cisco Sand	2,500	21	17	42	24	1952
16	Upton	Crockett	Grayburg Sand	1,500	0	0	7	0	1952
17	Mitchell	Southwest Westbrook	Clearfork	4,000	2	18	1	72	1955

CONCLUSIONS

The following findings have been drawn from experimental and field observations:

1. Due to unbalanced forces, the tool in operation moves immediately to contact the formation to provide zero stand-off for some of the nozzles.
2. Increased cutting, cleaning and scouring results in the area acted upon by the nozzles with the least stand-off. This indicates that the better cleaning job results from use of the decentralized tool.
3. Greater erosion of fractures in the test targets resulted from use of acid solution as compared to fresh water.
4. Average fluid production of field jobs as presented in Table 2 increased to 255% of the previous production.
5. Oil production was increased by treatment in most cases, and was dramatically improved in many cases.
6. The wells included in Table 2 ranged in age from 17 to 44 years. All had been previously stimulated.
7. Treatment volumes ranged from 1000-7000 gal. acid solution.
8. Caliper surveys verify hole enlargement due to treatment. See Fig. 11.
9. The self-decentralized hydra-jet treatment is a new and novel but proven approach to stimulate production in open-hole completed wells.

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ACKNOWLEDGMENTS

The authors wish to thank Skelly Oil Company and Halliburton Services for permission to publish this paper; the producing companies' personnel who expressed confidence in the technique, supplied the well candidates and histories; and the many Halliburton Field and Research personnel who participated in developing and testing the tools.