S-CAL RESEARCH CORPORATION

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METHOD FOR CUTTING STEAM HEAT LOSSES DURING CYCLIC STEAM INJECTION OF WELLS

Contract DE-FG49-93CE 15600

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FOURTH QUARTERLY REPORT

DETAILED DESIGN OF SLOT-CUTTING TOOL FOR "IN SITU" PERFORATION OF GRAVEL-PACKED HORIZONTAL WELLS

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ABSTRACT

Effective Gravel-packing of horizontal wells is difficult to achieve, using conventional pre-slotted liners, yet it is generally required in the soft Heavy Oil reservoir rocks of California, where cyclic steam injection has been proven to be the most cost-effective oil recovery method.

The proposed method of gravel placement behind a non-perforated liner, which is later perforated "in situ" with a new tool operated by coiled-tubing, is expected to greatly reduce costs resulting from sand production in horizontal wells operated under cyclic steam injection.

The detailed configuration of the prototype tool is described. It includes two pairs of cutting wheels at the ends of spring-loaded pivoting arms, which are periodically pressed through the liner wall and shortly thereafter retracted, while the coiled tubing is being pulled-out. For each operating cycle of the hydraulically-operated tool, this results in a set of four narrow slots parallel to the liner axis, in two perpendicular diametral planes. The shape of the edges of each slot facilitates bridging by the gravel particles, for a more effective and compacted gravel-packing.

The tool includes a few easily-assembled parts machined from surface-hardened alloy steel presenting great toughness, selected from those used in die making.

The operation of the system and potential future improvements are outlined.

The method of fabrication, detailed drawings and specifications are given. They will serve as a basis for negotiating subcontracts with qualified machine shops.

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FOURTH QUARTERLY REPORT

DETAILED DESIGN OF SLOT-CUTTING TOOL FOR "IN SITU" PERFORATION OF
GRAVEL-PACKED HORIZONTAL LINERS

1. PURPOSE OF THE TOOL:

Successful gravel-packing of Horizontal Liners with conventional pre-slotted tubulars is very difficult over long intervals in highly-deviated or horizontal wells. To address this problem, especially in the poorly consolidated Heavy Oil reservoirs of California, where steam injection is required, the technique which we have patented consists in using an un-perforated liner string, equipped with centralizers and in displacing a water-sand slurry under turbulent flow rate conditions in the deviated or horizontal annular

space behind the liner, in the same way that a cement slurry would be displaced for cementing. After entering the annulus, the flow velocity decreases and gravity segregation of the gravel particles becomes the dominant phenomenon, resulting in the gradual saltation of the gravel around the liner and centralizers. The upper part of the annulus remains gravel-free so that the gravel slurry continues to flow uphole until it gradually moves up over the full length of the annulus. A reverse circulation of the gravel slurry above the settled gravel layer may then be used to complete filling-up of the top of the annulus with gravel.

In weak or non-consolidated sands where the sand grains are held together mostly by the Heavy Oil, the injection of steam later results in the gradual sloughing of the hole roof above the gravel layer, so that sand production problems remain manageable provided that a sufficient volume of gravel was displaced behind the liner.

Liner perforation is a necessary step, but, if done with shaped charges guns, the jet hole entrance is usually so large that both the formation sand and gravel particles can flow through them. The "in situ" liner slot-cutting operation, performed with a coiled tubing unit after the curved part of the liner has been cemented, is designed to replace the round holes of the jet guns with narrow slots punched into the liner wall by a hydraulically-operated cutting tool, so as to prevent the coarse gravel particles from passing through. By using a punching tool rather than an abrasive cutting wheel, the edges of the slot are slightly curled outwards into the annulus, thus further compacting the gravel layer and facilitating the bridging of gravel particles across the slot and above it.

2. GENERAL DESCRIPTION OF THE SLOT-CUTTING TOOL

The basic element in the slot-cutting tool consists of a pair of cutting wheels periodically pressed into the liner wall, so as to punch them through. This creates a stress concentration at the extreme tip of the initial indentation, which is then more easily extended by pulling the wheel along the liner axis, so that the wheel, made of hard "chisel" steel, creates a slot, by a cold working process of the relatively thin metal wall. In this process, by plastic deformation, the fracture's edge is rolled outwards into the gravel. A similar metal-working process is used for cutting the thin gauge steel top plate of sealed cans containing food or beverages.

The next step is of retracting the arms at the end of which the wheels are mounted. The two parallel slots are thus ended leaving intact an interval of the liner, until the cutting wheels are again punched into the liner wall for starting the next pair of slots.

It is desirable to cut parallel slots in different diametral planes. This requires a series of such basic slot-cutting devices oriented in different planes. For the prototype tool, intended for use in a small 3.5" OD liner, only two pairs of cutting wheels, in two perpendicular planes, appear sufficient to provide the required fluid entry area, without excessive reduction of the strength of the liner after slotting.

3. DETAILED CONFIGURATION OF THE PROTOTYPE TOOL (see Fig.1)

The tool consists of two pairs of steel arms. Each arm is equipped with a cutting wheel at its downhole end. The two arms of each pair are articulated at the center of a diametral steel post. The diametral posts are in two perpendicular diametral planes of a tubular

steel housing in which a hydraulically-operated piston slides. To this piston are fastened: 1) a first tubular sliding device, equipped with four hardened steel rollers, which operates the first pair of arms, (one pair of rollers opens the arms, while the other pair closes them during the return motion of the sliding device),

2) a second identical sliding device operating the second pair of arms in a perpendicular plane, during the same sequence of operations,

3) a spring compressed by the force applied by the hydraulic piston.

The tubular housing is a short piece of 2.875" OD steel tubing with internal NL Bradford threads at both ends. The upper end is connected to the lower end of the coiled tubing and the lower end is plugged off by the spring support axial column. The housing also presents four lateral rectangular openings through which the cutting wheels may extend out to punch into the 3.5" OD (3.04" ID) liner. The upper part of the housing is the hydraulic cylinder in which the "O" ring-sealed piston slides. The two diametral posts are fastened to the housing by set screws and so are the two fixed transverse shafts around which the two pairs of arms rotate by a small angle, from their retracted position to their extended position. It is intended that the slot-cutting tool be dismantled, checked for wear, cleaned, lubricated and re-assembled after completion of each liner-slotting job. For this reason, the number of parts has been minimized and their assembly made as simple as possible, so that very high strength hardened alloy steels could be used in this tool, without regard to their susceptibility to potential corrosion by well fluids. Any beginning of corrosion is prevented by thorough cleaning and greasing of all parts prior to

re-assembly of the tool.

4. TOOL ASSEMBLY PROCEDURE

The "O" ring-sealed piston is threaded directly into the upper end of the assembly of the two sliding devices. The two diametral posts are positioned in their respective cavities of the sliding devices prior to insertion of this assembly into the bottom of the housing. The eight rollers are also pre-assembled in the two sliding devices where they are inserted through the windows through which the rotating arms pass through. All the rollers are held in place by clips. After setting the screws into the top and bottom of each diametral post, the two pairs of arms are then positioned respectively around each of the posts.

The first arm, with its pre-assembled cutting wheel, is inserted through the lateral opening in the housing. Each arm is ended by a fork, equipped with two porous bronze bushings and locking collars. With both arms of the upper pair positioned around the upper diametral post, the shaft is inserted through the bushings and post hole and fastened to the housing by sleeves and keys. The same procedure is repeated for the lower pair of arms.

The spring assembly, with its axial support is inserted into the bottom end of the lower sliding device and the bottom plug is fastened to the bottom of the housing.

5. SYSTEM OPERATION AND POTENTIAL IMPROVEMENTS

The coiled tubing is run-in to the bottom end of the 3.5"OD liner under a sufficient differential internal water pressure to maintain the spring compressed and the cutting

wheels retracted into the housing. The annular is open at the surface.

By suddenly releasing the tool cylinder's internal water pressure, the full force of the spring, applied to the bottom end of the lower sliding device, rapidly pushes both sliding devices upwards into the housing. In this motion, the four inner rollers spread open the two pairs of arms, while the four outer rollers are thrust clear out of the way of the opening arms. The four cutting wheels penetrate into the liner wall, while the coiled tubing is pulled-up at low speed. The translation of the tool causes the rotation of the cutting wheels, thus creating the first four parallel slots in the liner.

The control valve may be located either at the surface or downhole, but controlled from the surface by wireline, if it is desirable to avoid fatigue stresses in the coiled tubing resulting from shock waves associated with such repeated fluid pressure variations.

If a downhole control valve is used, a minor modification of the piston may change its operation to that of a double-acting piston if additional force is required during the initial penetration of the liner wall. This feature might be useful in thick-wall liners.

The compartment of the housing occupied by the spring may be made gas-tight by adding inner and outer "O" ring seals to the lower end of the lower sliding device. This provides an additional gas spring force, if required to punch through heavy wall liners. It also reduces the required water pressure in the coiled tubing, to partially balance the downhole hydrostatic pressure.

By pumping water into the cylinder to raise its pressure against the spring's opposing force, the sliding devices are more gradually returned to their lower position. In this motion, the outer

rollers, acting on the outside edge of the arms, retract them into the housing, while the tool moves uphole to a new position, where the whole process is repeated, to produce a new set of four slots.

The length of each slot is dependent upon the moving speed of the coiled tubing and upon the time interval between successive pressure releases, which itself is limited by the pumping rate of water into the coiled tubing, while it is coiled up.

If necessary, additional tools may be connected in series to the coiled tubing, so as to reduce the time required for cutting slots in long liners. In that case, the hydraulic pressure may be transmitted to each housing either through external steel tubings when the liner diameter is larger than 3.5"OD, or through holes machined, or preferably cast, in the side wall of the sliding devices. This improvement will only be included in the series production of the tool, if there is a sufficient market for a justification of its added fabrication cost.

6. METHOD OF FABRICATION OF THE TOOL

The four cutting wheels are identical. They are made of alloy steel presenting both a high hardness and high toughness so that the wheel may withstand all the successive impacts corresponding to each set of four slots along the gravel-packed liner length. These steel qualities are obtained by suitable alloy compositions and heat treatments, commonly used in chisel or die making.

The steel shafts and bronze bushings of all cutting wheels are all identical and available from various suppliers.

The arms are also made of alloy steel which is first machined according to the drawings and specifications of Fig. 2 and surface-hardened by a suitable heat treatment for the selected alloy

steel. The hard surfaces are required especially at the arms' edges where rollers apply large local forces.

The rollers are also made of hardened steel subsequently covered by a hard chrome layer.

The diametral posts are machined according to Fig.3 and their shaft hole is also surface hardened.

The arm shafts, bronze bushings and locking collars are available from various suppliers. The shafts are also plated with a hard layer of chrome.

The two sliding devices are identical. They are machined from bar stock in the prototype, according to Fig.4, but would be made from cast steel when produced in series, and surface hardened to withstand the high local forces applied by the rollers.

The spring is made of a stack of Belleville rings threaded around a tubular support. The effective spring length may easily be varied by changing the number of rings, during shop tests.

The piston is machined, including an "O" ring groove. It is chrome-plated to facilitate its sliding motion inside the cylinder part of the housing.

The housing is made from a piece of 2 7/8" OD tubing machined as indicated on Fig.5 and chrome-plated on its inner surface.

7. CONCLUSIONS

The patented conceptual design of a coiled tubing tool for "in situ" slot-cutting of small gravel-packed horizontal liners has been refined to the point that a prototype can now be built and shop-tested prior to a field test.

The modular design lends itself to low-cost serial machining

techniques and easy cleaning in the shop, without compromising the tool's characteristics.

The shafts and bearings, which, together with the cutting wheels, are expected to wear out first, are easily replaceable at low cost. All other elements are inherently long-lasting with regular maintenance.

The prototype tool will easily be adapted to various shop test conditions and liner characteristics.

The tool may be improved by using one cast steel element for the sliding device, when the tool is built in series.

SUBJECT GENERAL CONFIGURATION OF
SLOT-CUTTING TOOL

FIG. 1 B

SHEET NO. 2 OF 1

FILE DOE 600

DATE 2/1/95

BY MG

SUBJECT DETAILED CONFIGURATION OF
SLOT-CUTTING TOOL (SCALE 1"/1")

FIG. 2

SHEET NO. 3 OF 7

FILE DOE 600

DATE 02/01/95

BY M.L.

SUBJECT

DETAILED DRAWINGS OF AN
ARMS PAIR AND A WHEEL

UPPER ARM (Scale 1" = 1")

LOWER ARM

Material: Surface Hardened "Chisel" Alloy Steel

Machining: 1 micro inch on all contact Surfaces $\nabla \nabla$
+ chrome-plated hard layer $\nabla \nabla$

Porous Bronze

$5/8"$ OD, $1/2"$ ID

Section DD

Section BB

Section AA

Section FF

Section EE

WHEEL

Porous Bronze

$1/2"$ OD, $3/8"$ ID

Section CC

G

Section GG

SUBJECT DETAILED DRAWINGS OF
DIAMETRAL POST / SHAFT

Material: Surface-Hardened Alloy Steel

Machining: 1 Micro-inch tolerance on all contact Surfaces
+ Chrome-Plated Hard Layer

FIG. 4

SHEET NO. 5 OF 7

FILE DOE 600

DATE 2/1/95

BY MGR

SUBJECT DETAILED DRAWINGS OF
SLIDING DEVICE (Scale 1"=1")

SUBJECT DETAILED DRAWINGS
OF TOOL HOUSING

Material: Steel Tubing API Grade P105

Machining: 2 Micro-inch Tolerance + Chrome-Plated Hard Layer on internal surface

SUBJECT DETAILED DRAWINGS
OF TOOL HOUSING