166/308

SEARCH ROOM

CROSS REFERENCE

July 6, 1965 J. L. HUITT ETAL 3,193,012

METHOD OF CUTTING A NOTCH IN AN UNDERGROUND FORMATION PENETRATED BY A WELL

Filed May 29, 1961 2 Sheets-Sheet 1

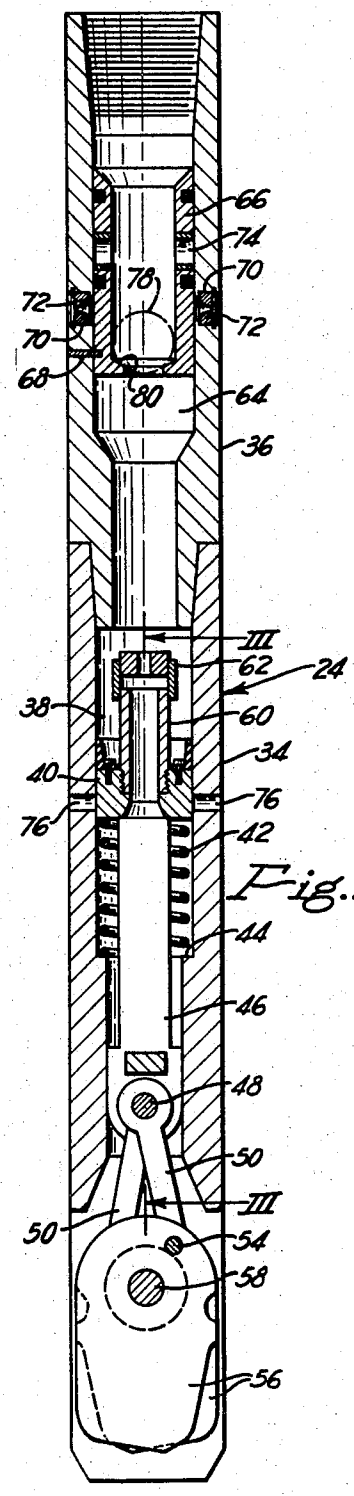


Fig. 2

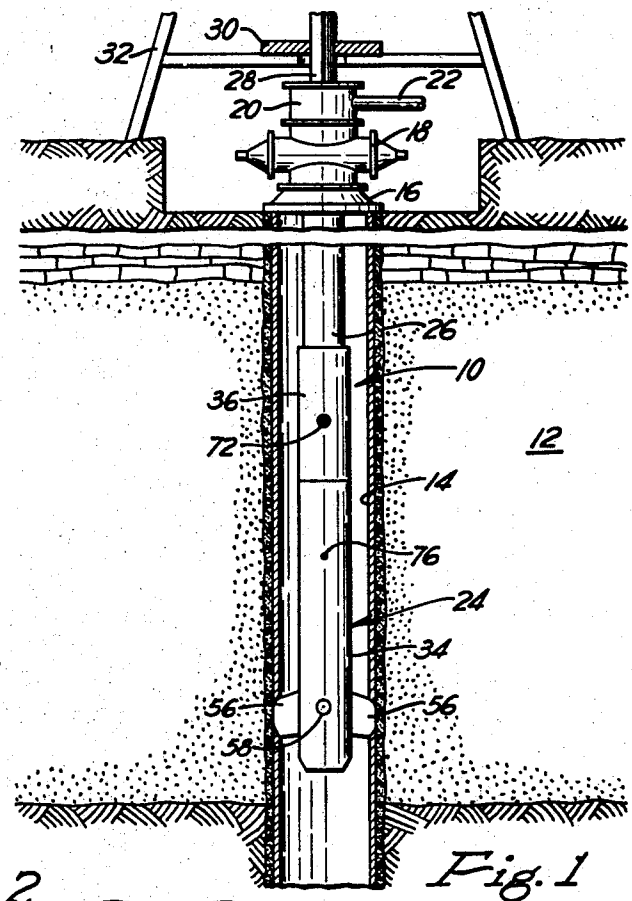


Fig. 1

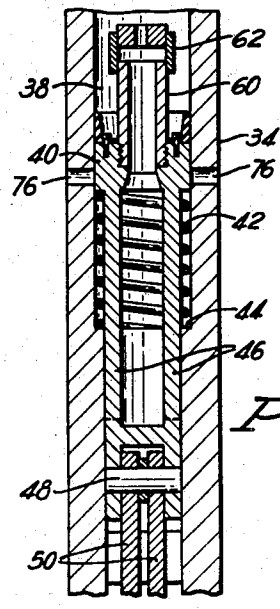


Fig. 3

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METHOD OF CUTTING A NOTCH IN AN UNDERGROUND FORMATION PENETRATED BY A WELL

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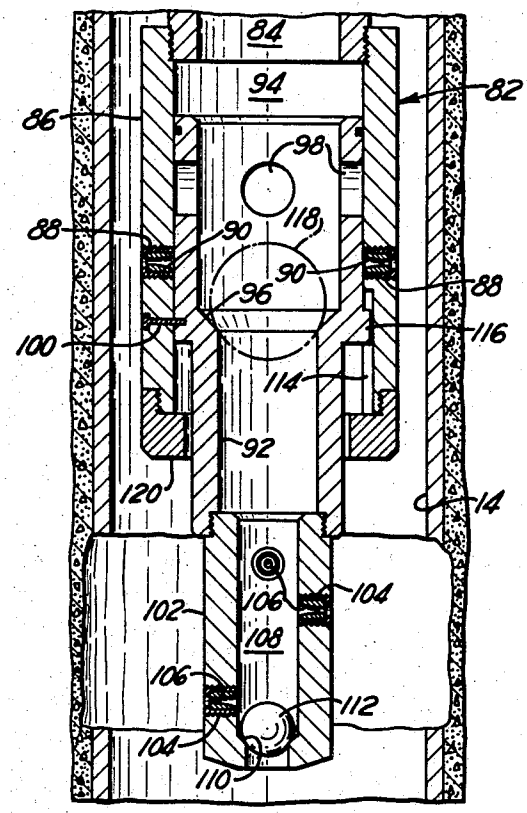


Fig. 4

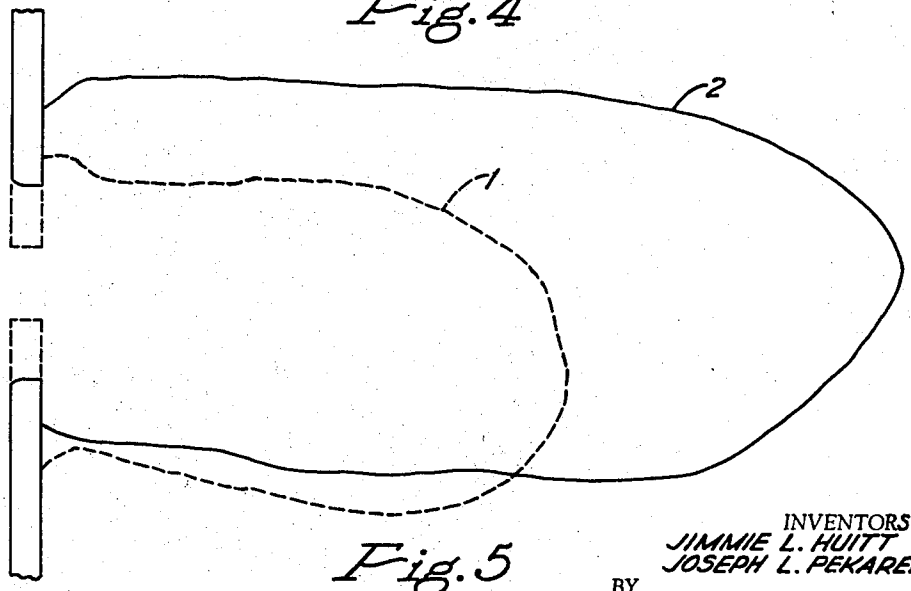


Fig. 5

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METHOD OF CUTTING A NOTCH IN AN UNDERGROUND FORMATION PENETRATED BY A WELL

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This invention relates to the fracturing of subsurface formations penetrated by a well, and more particularly to a method of cutting a notch in such formations for the initiation of a fracture.

It has become common practice to create fractures extending from the borehole of a well into a subsurface formation to increase the productive capacity of the well regardless of whether the well is used in the primary production of fluids from the subsurface formation or is an injection or production well used in a secondary recovery process. The fractures are created by pumping a liquid down the well and applying a pressure, usually called the "breakdown" pressure, adequate to overcome the tensile strength of the subsurface formation and the weight of the overburden.

It is important, if the maximum improvement in the capacity of the well is to be obtained by fracturing, that the fracture be properly located and oriented. In the Dismukes Patent No. 2,699,212 a process is described for the accurate location and orientation of the fracture. In that process, a notch is cut in the borehole wall to create a plane of weakness and increase the surface subjected to the pressure applied to the fracturing fluid to cause the fracture to form as an extension of the notch. The notch also lowers the breakdown pressure required to fracture the formation.

It is advantageous to fracture wells that have been cased through the zone to be fractured. The pressure of the fracturing fluid is then applied to the formation only at an opening that has been cut in the casing at the desired location; hence, accurate control of the location of the point of initiation of the fracture is assured. Notches cut in the subsurface formation to be fractured are advantageous in fracturing a formation from a well in which casing has been set because of the reduced pressure that is necessary to create the desired fracture. Frequently, the breakdown pressure exceeds the pressure that may be applied to the casing if a notch has not been cut in the borehole wall. It is then necessary to set a packer in the casing isolating the opening through which the fracture is to be made from the remainder of the casing and run tubing through the packer for delivery of the fracturing fluid into the isolated portion of the casing.

One of the methods that has been widely used for cutting a notch in a subsurface formation for initiation of a fracture employs a fluid which is directed at a high velocity from a nozzle against the borehole wall. The fluid may be a liquid, which may be a corrosive liquid such as an acid, or a suspension of abrasive particles in a liquid or gas. This method, usually referred to as hydraulic cutting, is faster than the cutting of a notch with a mechanically operated tool. Moreover, the hydraulic cutting of the desired notch does not require a rotary rig, as do mechanical tools adapted to cut a horizontal notch, thereby allowing a substantial saving in the cost of the undercutting operation. However, in some instances the marked reduction in breakdown pressure and accurate location of the fracture that is obtained when a notch is cut by hydraulic means in an open hole have not been realized when an abrasive slurry is used to cut the desired notch in a cased well.

This invention relates to a method of hydraulically cutting a notch in a formation penetrated by a cased well for the initiation of a fracture in which an opening of substantial width is cut through the casing, and thereafter a hydraulic cutting fluid is discharged from a nozzle through the opening in the casing to cut the desired notch in the subsurface formation. The width of the opening cut in the casing is at least four times the diameter of the nozzle.

In the drawings:

FIGURE 1 is a diagrammatic illustration, partially in vertical section, of apparatus for use in the process of this invention in which a mechanical tool is used to cut an opening in the casing;

FIGURE 2 is a vertical sectional view of the cutting tool and nozzle used in the embodiment of the invention illustrated in FIGURE 1;

FIGURE 3 is a vertical sectional view along the section line 3—3 in FIGURE 2 of the apparatus for cutting the opening in the casing;

FIGURE 4 is a sectional view of a preferred embodiment of this invention in which the opening of substantial width in the casing is cut hydraulically; and

FIGURE 5 shows a comparison of the configuration of a notch cut in the subsurface formation by the process of this invention with notches cut when the same nozzles used to cut the notch in the formation are used to cut the opening in the casing.

We have discovered that the removal of a section of the casing substantially larger than the diameter of the stream discharged from the nozzle used to cut the notch in the formation prior to cutting the notch in the formation allows the creation of a notch extending a greater distance radially from the casing into the formation. The nozzles ordinarily used for the cutting of casing or the cutting of notches in subsurface formations by hydraulic means have a diameter not exceeding ¼ inch. A preferred nozzle has an opening with a diameter of 3/16 inch. In the process of this invention, the opening cut in the casing has a width at least four times the diameter of the opening in the nozzle used to cut the notch in the formation. The maximum width of the opening in the casing is governed by considerations other than those important to this invention. Ordinarily, there is no improvement in the depth or shape of the notch cut in the formation if the opening in the casing is more than about ten times the diameter of the nozzle used to cut the notch in the formation. The removal of a section of the casing greater than approximately ten times the diameter of the nozzle used to cut the notch in the formation may be objectionable because of the exposure of a larger area of the formation with a resultant diminishing accuracy of location of the fracture.

Although the reason for the increased depth of cut into the formation made possible by the process of this invention is not known with certainty, it is believed that when the opening in the casing is the result only of discharging a stream of cutting fluid from the nozzle used to cut the notch in the formation, the opening in the casing does not have sufficient area to allow cutting fluid to flow back into the borehole of the well after striking the outer portion of the cut without interfering with the flow of cutting fluid outwardly from the nozzle. Apparently, the backflow of hydraulic fluid from the outer portion of the notch cut into the borehole of the well is not at a high enough velocity to cut the casing and increase the opening in the casing to a width which will eliminate the interference with the outwardly flowing stream discharged from the nozzle.

A series of tests was run to determine the effect of increasing the width of the opening in the casing through which a high velocity stream of water and sand is directed

to cut a notch in the subsurface formation. A target was prepared from a 24-inch section of 20-inch O.D. seamless steel casing having a wall thickness of 0.438 inch. The ends of the casing were closed with 20-inch extra strong seamless steel welding caps. An opening was cut in one of the welding caps to receive 5½-inch O.D. 17 lb./ft. casing which was etxended down into the target to a depth about 4 inches from the bottom of the target and welded in place at the opening. The lower end of the 5½-inch O.D. casing was closed with a 5-inch extra strong seamless steel welding cap. Two openings were cut in the end of the target near the opening for the 5½-inch O.D. casing to receive 1 inch couplings. The annular space between the 5½-inch casing and the 20-inch casing was filled with a 15 lb./gal. neat Portland cement. The cement was set under 700 p.s.i. pressure for a period of at least 14 days. An opening outside of the target in the 5½-inch casing was fitted with a 2-inch coupling to which suitable valves were connected for control of the back pressure during the cutting of the notch in the casing in the cement surrounding the casing.

A 2-inch pipe having a hydraulic nozzle head mounted at its lower end to direct an abrasive slurry laterally against the 5½-inch O.D. casing was extended down through the 5½-inch O.D. casing. Suitable connections were provided for supplying the hydraulic slurry under pressure into the 2-inch pipe, to allow rotation of the 2-inch pipe within the 5½-inch O.D. casing, and to control the flow from the 5½ inch O.D. casing whereby the desired pressure could be maintained in the annulus between the 2-inch pipe and the 5½-inch O.D. casing. An abrasive slurry of water containing sand in a concentration of 1½ lb./gal. was pumped down through the 2-inch pipe and discharged from the nozzle against the 5½-inch O.D. casing while a back pressure of 700 p.s.i. was maintained inside the 5½-inch O.D. casing. The 2-inch pipe was rotated at a rate of 6 r.p.m. The cutting action was discontinued periodically and the depth of the notch cut in the formation measured.

Several different nozzle heads were used to cut the opening in the casing and the notch in the cement surrounding the 5½-inch O.D. casing. In Tests No. 1, 2, and 3 all of the nozzles were in the same horizontal plane and the same nozzles were used for cutting the opening in the casing and the notch. In Test No. 4 the nozzle head used for cutting the opening in the casing had three nozzles arranged in a spiral around the nozzle head. In Test No. 5 the nozzle head had four nozzles arranged in a spiral similar to the lower nozzle body illustrated in FIGURE 4. Nozzle heads with the individual nozzles arranged in the same horizontal plane were used in every test to cut the notch in the cement. The results of the tests are set forth in Table I.

Table I

Test No.	Width of Casing Opening, in.	No. of Nozzles for Cutting Notch	Depth of Notch Beyond Casing After Cutting for				
			7 min.	12 min.	15 min.	17 min.	20 min.
1	½	3	-------	-------	4¼	-------	4¼
2	½	4	-------	-------	4¼	-------	4¼
3	½	3	-------	-------	3¾	-------	-------
4	1⅛	3	2¾	4¾	-------	5¼	-------
5	1½	4	3¼	5¼	-------	6¾	-------

It will be noted from Test No. 1 in which a section ½ inch wide was removed from the casing by means of the nozzles used to cut the notch in the target that the maximum diameter of the notch was 14 inches after a 20-minute cutting period. Because there was no increase in the notch diameter after a 20-minute cutting period over the notch diameter after a 15-minute cutting period, the maximum notch diameter apparently had been obtained. By increasing the width of the section removed from the 5½-inch casing to 1⅛ inch, the maximum diameter of the notch was increased to 17 inches in a 17-minute cutting period. Moreover, the diameter of the notch was increased 2 inches by increasing the cutting period from 12 to 17 minutes. Hence, a further increase in the notch diameter may have been obtained if a longer cutting period had been used.

An even greater increase in the diameter of the notch was obtained with a cutting tool having four nozzles, as is shown by comparison of Tests Nos. 2 and 5. In Run No. 5 in which the width of the section removed from the casing was 1½ inches, a maximum notch diameter of 19 inches was obtained. That notch diameter was equal to the inside diameter of the 20-inch casing used in construction of the target. Moreover, there was an approximately 3-inch increase in diameter during the last 5 minutes of the cutting period. The area of the formation exposed by the notch in Test No. 5 was approximately twice the area of the formation exposed by the 14-inch notch of Test No. 2.

Referring to FIGURE 5 in which the configuration of the notch **1** cut during Test No. 2 is compared with that of the notch **2** cut in Test No. 5, it will be noticed that the increased length of the notch is obtained with substantially no change in width. The longer, narrower shape of the notch obtained in Test No. 5 provides a greater concentration of forces at the apex of the notch and more accurately fixes the plane of the fracture. Moreover, notches formed through narrower openings in the casing tend to approach the wall of the casing at an acute angle, as a result of which upon application of pressure during the fracturing operation, substantial forces tending to separate the formation from the casing are created. The notches formed through wide openings in the casing approach the outer surface of the casing at an obtuse angle which minimizes forces tending to separate the casing from the formation during the subsequent fracturing. The notches formed actually are more irregular than indicated in FIGURE 5 which indicates an average of the shape of cross sections taken along different radii, and permits a more accurate comparison of the two notches.

One embodiment of the invention is illustrated in FIGURES 1 to 4 for the mechanical removal of a section of the casing to form the desired wide opening. Referring to FIGURE 1, a well indicated generally by reference numeral **10** is illustrated with a borehole extending through the pay zone **12**. Casing **14** is set completely through the pay zone. The well is illustrated with its upper end closed at the surface by a casing head **16** on which a blowout preventer **18** is mounted. A T **20** on the upper end of the blowout preventer **18** has a lateral outlet for connection to a line **22** for discharge of a circulating fluid.

Within the casing near the lower portion of the pay zone **12** is the tool, indicated generally by reference numeral **24**, for cutting the opening in the casing and the notch in the pay zone **12**. The tool **24** is connected at its upper end to drill pipe **26** connected to the lower end of a kelly **28** which is illustrated extending upwardly from the T **20** through a rotary table **30** mounted on a rotary rig **32**.

Referring to FIGURE 2, tool **24**, which is illustrated in vertical section, is made up of a tubular housing **34** connected at its upper end to a hydraulic nozzle head **36** which is suitably threaded at its upper end for connection to the lower end of the drill pipe **26**. Housing **34** has a central passage **38** extending through it in which a piston **40** is adapted to slide. Piston **40** is urged upwardly by a helical spring **42** which engages the lower surface of the piston **40** and a shoulder **44** extending from the inner surface of passage **38**. Extending downwardly from piston **40** are spaced connecting rods **46** between which an arbor **48** extends. A pair of pivot arms **50** adapted to rotate on the arbor **48** are connected by means of pivot pins **54** to a pair of cutters **56** which are rotatably

mounted on an axle 58 extending between opposite faces of the housing 34. One of the pivot arms 50 is connected to the cutter 56 on one side and the other pivot arm 50 to the cutter 56 on the opposite side of the center line between arbor 48 and axle 58 to cause the cutting elements to move in opposite directions as the piston 40 is forced downwardly. A tubular neck 60 in the piston 40 has an orifice insert 62 which permits a limited flow through the piston 40.

Hydraulic nozzle head 36 has a central passage 64 extending lengthwise through it in which a sleeve 66 is slidably mounted. During the period when a section is cut from the casing, sleeve 66 is held in the upper position illustrated in FIGURE 2 by a shear pin 68. A plurality of nozzle ports 70 adapted to receive nozzle inserts 72 are provided in the wall of the hydraulic nozzle head 36 for the discharge of a cutting fluid during the cutting of a notch in the formation. Openings 74 in the wall of sleeve 66 are located for alignment with the nozzle port 70 upon shearing of shear pin 68 and movement of the sleeve 66 to its lower position.

In the operation of the apparatus illustrated in FIGURES 1 through 3, the tool 24 is suspended with the cutters 56 at the desired elevation by means of drill pipe 26. A circulating liquid is pumped down through the kelly 28 and the drill pipe 26 and through the hydraulic nozzle head 36 into the housing 34 while the tool is rotated by means of the kelly 28 on rotary table 30. The pressure drop through orifice 62 causes downward movement of the piston 40 which in turn causes the cutters 56 to rotate to an extended position at which they engage the casing. The cutters 56 are shaped to cut an opening of the desired width in the casing. Rotation of the tool 24 and circulation of the circulating liquid is continued until the piston 40 descends to a level below relief ports 76 at which position the cutters 56 are fully extended and the desired opening has been cut completely through the casing 14. The pressure on the circulating liquid drops to indicate when the casing cutting operation is completed. Thereafter, the flow of the circulating liquid is stopped and the spring 42 returns the piston 40 to the position illustrated in FIGURE 2 of the drawings.

The tool is then lowered on the drill pipe 26 a distance adapted to bring the orifice ports 70 in alignment with the opening cut in the casing by the cutters 56. A ball 78 is dropped down the drill pipe to come to rest on a valve seat 80 at the bottom of sleeve 66. Liquid is then pumped into the upper end of the drill pipe under pressure sufficient to shear shear pin 68 and cause sleeve 66 to move downwardly and bring openings 74 into alignment with the nozzle ports 70. A hydraulic cutting fluid such as an abrasive slurry of sand suspended in water is pumped down the drill pipe 26 and through the nozzle 72 for a period adequate to cut the desired notch.

A preferred tool for use in this invention in which both the opening in the casing and the notch are cut hydraulically is illustrated in FIGURE 4. Referring to that figure, the tool, indicated generally by reference numeral 82, illustrated suspended on the lower end of a string of tubing 84, consists in an upper nozzle body 86 having a plurality of nozzle ports 88 positioned in a single horizontal plane. Nozzle inserts 90 of a suitable hard metal such as tungsten carbide are mounted in the ports 88 by any suitable means such as the screw threads illustrated in FIGURE 4. Fitting slidably within the upper body 86 is a sleeve 92 having an upper section of large diameter connected to a lower section of smaller diameter by a sloping surface 96 which serves as a valve seat. Above the level of surface 96 are openings 98 extending through the wall of sleeve 92 in position for alignment with the nozzle ports 88. The sleeve 92 is held in the upper position illustrated in FIGURE 4 with the openings 98 out of alignment with the nozzle ports 88 by a shear pin 100 during the period the opening is cut in the casing.

Connected to the lower end of sleeve 92 is a lower nozzle body 102 having nozzle ports 104 extending through it. The number and location of the nozzle ports 104 is designed to cause the stream discharged from the nozzle to overlap and thereby remove a continuous section without intervening strips of metal. The number of nozzle ports 104 will be determined by the width of opening that is desired in the casing. In the apparatus illustrated in FIGURE 4, the lower nozzle body 102 is provided with four nozzle ports 104 pointing in directions separated by 90° from one another. A nozzle insert 106 of suitable hard material is mounted in each of the nozzle ports 104. The size of the central opening 108 in the lower body 102 is decreased at the lower end of the lower body to provide a valve seat 110.

In the operation of the apparatus illustrated in FIGURE 4, the hydraulic tool 82 is run into the well on tubing 84 to the desired depth. A ball 112 of proper size to engage the valve seat 110 and close the lower end of the tool 82 is dropped down the tubing. Thereafter, an abrasive slurry is pumped down the tubing and discharged from the nozzles 104 while the tubing is rotated. Rotation of the lower nozzle body 102 with the tubing 84 is accomplished by means of a spline 114 in the lower end of upper nozzle body 86 which is engaged by a key 116 extending from the outer surface of the sleeve 92. The rotation of the tool and the pumping of the cutting fluids through the nozzles of the lower nozzle body is continued for a period adequate to cut an opening in the casing. The tool 82 is then lowered a distance adequate to bring the nozzle ports 88 into alignment with the center of the opening cut in the casing wall. A ball 118 is then dropped down the tubing to engage surface 96 to close the lower end of sleeve 92. Liquid pressure is applied to break the shear pin 100 and move the sleeve 92 to a lower position at which passages 98 are in alignment with the nozzle ports 88. Downward movement of the sleeve 92 is limited by a retaining ring 120 at the lower end of the upper nozzle body. The tool is then rotated as before while a cutting fluid is pumped down the tubing and through the nozzles 90 to cut the desired notch in the subsurface formation.

This invention has been described for processes and apparatus adapted to cut a continuous ring from the casing and a continuous horizontal notch in the surrounding formation. The invention can also be used for cutting other types of holes in the formation for facilitating fracturing. For example, it may be desirable to make a series of holes, instead of a slot, in the formation hydraulically by not rotating the nozzle during the cutting operation. The advantages of this invention can then be realized by cutting a hole in the casing having a substantially larger diameter than the diameter of the nozzle used to cut the hole in the formation.

We claim:

1. A method of hydraulically cutting a notch in a subsurface formation penetrated by a well having casing set therein by means of a high velocity stream of a cutting fluid discharged from a nozzle for initiation of a fracture in the subsurface formation, comprising cutting a circumferential opening in the casing wall having a width at least four times the diameter of the nozzle at the desired depth to expose the subsurface formation, thereafter centering a nozzle opposite the circumferential opening and directing a high velocity stream of a cutting fluid from the nozzle through the circumferential opening in the casing wall to cut a notch in the formation, and rotating the nozzle about a vertical axis and in a horizontal plane adapted to direct the high velocity stream through the circumferential opening while discharging the high velocity stream of a cutting fluid from the nozzle.

2. A method of hydraulically cutting a notch by means of a high velocity stream of a cutting fluid discharged from a nozzle in a subsurface formation for the initiation of a fracture in the formation, said formation being penetrated by a well casing

set therein, comprising running a mechanical milling tool into the casing to the desired depth, rotating said milling tool about a vertical axis to cut a circumferential opening in the casing with said mechanical tool, said opening having a width at least four times the diameter of the nozzle, thereafter centering the nozzle having a diameter less than one-fourth the width of the opening opposite the opening in the casing, pumping a hydraulic cutting fluid down the well and discharging said hydraulic cutting fluid through the nozzle at high velocity through the opening in the casing, and rotating the nozzle about a vertical axis and in a horizontal plane to cut the notch in the formation.

3. A method of hydraulically cutting a notch for the initiation of a fracture in a subsurface formation penetrated by a well having casing set therein comprising directing a high velocity stream of cutting fluid against the inner surface of the casing wall, rotating said high velocity stream about a vertical axis to cut a circumferential opening through the casing wall, directing a second high velocity stream of cutting fluid against the casing wall at a location overlapping but vertically displaced from the circumferential opening and rotating said stream about a vertical axis to enlarge the circumferential opening in the casing wall, thereafter centering a nozzle having a diameter less than one-fourth the width of the circumferential opening opposite said circumferential opening, directing a high velocity stream of cutting fluid from the nozzle radially outward through the circumferential opening in the casing to cut a notch in the formation, and rotating the nozzle about a vertical axis and in a horizontal plane

whereby the notch cut in the formation extends continuously around the casing.

4. A method of hydraulically cutting a notch in a subsurface formation for the initiation of a fracture in the formation, said formation being penetrated by a well having casing set into the formation comprising simultaneously directing a plurality of high velocity streams of cutting fluid against the casing wall at positions overlapping but vertically displaced from one another, rotating said high velocity streams around a vertical axis to cut a circumferential opening through the casing, thereafter centering a nozzle having a diameter less than one-fourth the width of the circumferential opening opposite said opening, discharging a high velocity stream of cutting fluid from said nozzle, and rotating said nozzle about a vertical axis and in a horizontal plane while discharging the high velocity stream from the nozzle to cut a notch in the formation.

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BENJAMIN HERSH, *Primary Examiner.*

BENJAMIN BENDETT, *Examiner.*

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,193,012 July 6, 1965

Jimmie L. Huitt et al.

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 6, line 75, after "well" insert -- having --.

Signed and sealed this 4th day of January 1966.

(SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

EDWARD J. BRENNER
Commissioner of Patents