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JET PERFORATOR FOR WELL CASINGS

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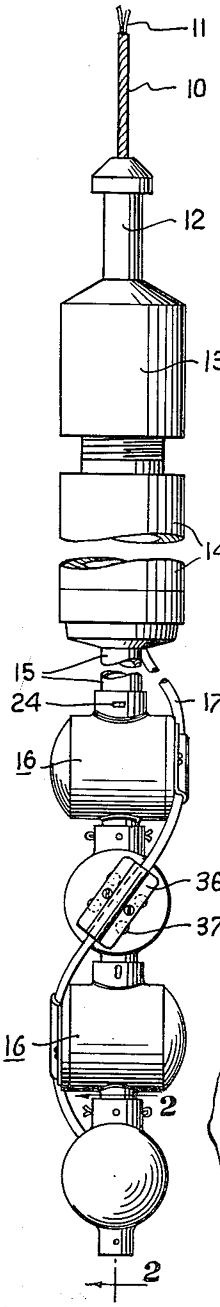

Fig. 1

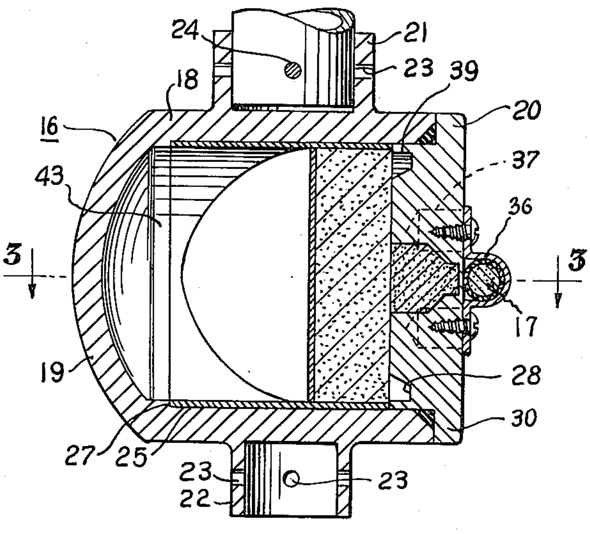

Fig. 2

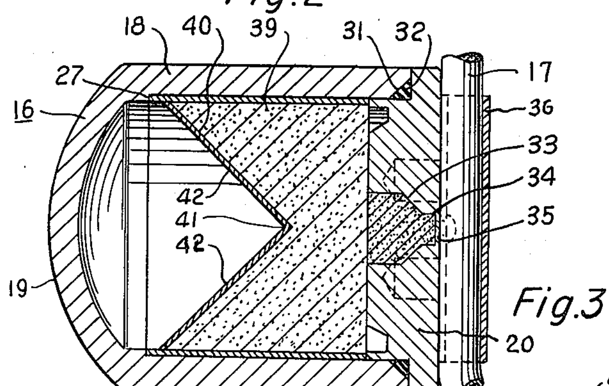

Fig. 3

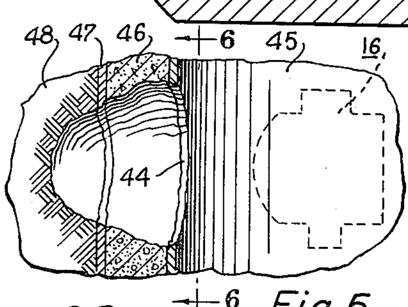

Fig. 5

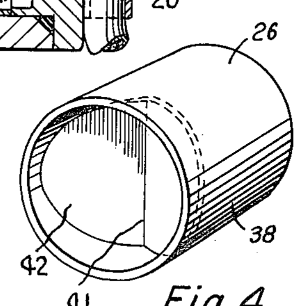

Fig. 4

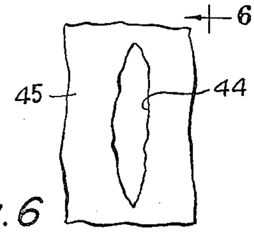

Fig. 6

INVENTORS
Edwin David Edwards
Ralph J. Hach

BY Ashley & Ashley

ATTORNEYS

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JET PERFORATOR FOR WELL CASINGS

Edwin David Edwards, Wichita Falls, and Ralph J. Hach, Plano, Tex., assignors to Advanced Oil Tools, Inc., Wichita Falls, Tex., a corporation of Delaware

Continuation of application Ser. No. 629,836, Dec. 21, 1956. This application Feb. 19, 1960, Ser. No. 9,652
8 Claims. (Cl. 102—20)

This invention relates to new and useful improvements in jet perforators for well casings.

The invention is particularly concerned with jet perforating guns which cut an elongate vertical slot in the well pipe or casing rather than the substantially circular opening now obtained by conventional jet perforating guns.

It is conventional practice to employ shaped charges, utilizing the Monroe effect, for the perforating of well casing or pipe when it is desired to open one or more passageways from the interior of the pipe into the earth formation. Thus, it is well-known to drill a well bore through a producing formation, and after the well casing or casings have been set or cemented in position, to perforate through the casings and cement into the producing formation so that the desired petroleum products, such as crude oil, may flow from the formation into the well pipe for recovery. Obviously, the size or diameter of the perforation is limited in that the well casing must not be too greatly weakened, and the larger the cross-sectional area of a circular perforation, the greater the extent to which the pipe is diminished in strength. Further, the closeness of spacing of the perforations is limited in that each perforation requires an explosive charge of a certain minimum weight, and the aggregate weight of the various explosive charges, all of which are exploded substantially simultaneously, is subject to a very definite maximum value. Thus, no more than a certain gross weight of explosive must be detonated within a well bore at one time for fear of excessive damage to the well pipe, or more importantly, excessive damage to the layer or layers of cement in which the pipe is set.

In view of the foregoing, it is apparent that a vertical slot in the pipe is desirable in that greater flow areas, or flow passages of greater cross-sectional area, are provided without excessive weakening of the pipe or casing. Further, the larger flow area obtained permits the utilization of fewer charges or shots, and the permissible maximum gross weight of explosive which may be detonated at one time in a well bore, is not so quickly approached.

It is, therefore, one object of this invention to provide an improved jet perforator for well bores utilizing a shaped charge which will produce a vertical slot in the well pipe and extending into the earth formation.

A further object of the invention is to provide an improved jet perforator for well pipe in which a slot-cutting, shaped charge is contained in a cylindrical housing whereby compact and closely-spaced housings may be employed for any desired vertical spacing of the slots cut in the well pipe, and further, whereby the longitudinal axis of the slot may be varied at will if such variation is found desirable or necessary.

Yet another object of the invention is to provide an improved jet perforator for well pipes in which a charge and a charge housing of certain proportions and dimensions

lends itself to efficient use in well pipes of varying diameters, in which the necessary manufacturing tolerances for the charge may be achieved with consistency, and by means of which a slot of the general shape of an elongate, narrow, ellipse is cut in the well pipe.

A construction designed to carry out the invention will be hereinafter described, together with other features of the invention.

The invention will be more readily understood from a reading of the following specification and by reference to the accompanying drawing, wherein an example of the invention is shown, and wherein:

FIG. 1 is a view in elevation illustrating a well perforating gun constructed in accordance with this invention and adapted for utilization of jet perforating charges constructed in accordance with this invention,

FIG. 2 is an enlarged, vertical, sectional view taken upon the line 2—2 of FIG. 1, the plug or rearward portion of the charge housing being rotated slightly to illustrate the mounting of the firing cord thereon,

FIG. 3 is a horizontal, cross-sectional view taken upon the line 3—3 of FIG. 2,

FIG. 4 is a view in perspective of the charge,

FIG. 5 is a vertical, cross-sectional view illustrating the general type of perforation obtained by this charge, and

FIG. 6 is a view in elevation illustrating the shape of the slot cut by this charge in the well pipe.

This application is a continuation of our co-pending application, Serial No. 629,836, filed December 21, 1956, now abandoned.

In the drawings, the numeral 10 designates a conventional perforating gun cable of the well-known type including strands of steel wire for support purposes, and a pair of electrical conductors 11 for supplying an electrical firing current to the perforating gun. The lower end of the cable is secured in a rope socket 12 carrying a gun head 13 to which is connected, a firing mechanism 14 containing the conventional firing charge or cap which is adapted to be detonated electrically. This general assembly and type of structure is well-known in the art and conventional in nature.

A supporting tube 15 depends from the lower portion of the element 14 and carries one or more jet perforating assemblies 16. The tube 15 is desirably lightweight in nature and functions to space the self-destroying assemblies 16 from the head assembly 13 and 14 so that the latter may be withdrawn from the well bore without having undergone appreciable damage when the several charges are fired. Lightweight aluminum tubing has been found quite suitable for fabrication of the tube 15. As will be explained more fully hereinafter, each of the jet perforation assemblies 16 receives an explosive cord 17 leading from a conventional detonating cap (not shown) carried within the body 14 and adapted, to be fired electrically. The cord 17 may be the widely known Prima Cord, a commercially available product in widespread use for delivering an explosive force to a number of spaced points, or any suitable explosive cord of the well-known types which contain detonating explosives which generate very high velocity explosive waves or forces. Examples of such explosives are pentaerythritol-tetranitrate, known as PETN, Tetryl, Pentolite, composed of PETN and TNT, Trinitrotoluene, known as TNT, Amatol, Cyclonite, RDX, Tetrytol, composed of Tetryl and TNT, and other explosives, all of which are well-known and are commercialy available. Upon the supplying of an electrical firing current through the conductors 11, the detonating cap is exploded in the usual fashion and in turn, detonates the firing cord 17 which almost instantaneously conducts an explosive force or wave to each of the assemblies 16, resulting in detonation of the latter.

The jet perforator assemblies 16 include a cylindrical housing 18 having one end closed by an integral, dished head 19, and the other end open to receive a closure or sealing plug 20. A tubular collar or boss 21 extends radially upwardly from the upper wall of the housing 18, and a similar, tubular collar or boss 22 extends radially downwardly from the lower wall of the housing. The outside diameter of one of the bosses 21 and 22 is of such magnitude to permit it to slip within the other or larger boss of a similar jet charge housing, in the particular embodiment illustrated in the drawings, the lower boss 22 being of such outside diameter as to slip readily within the upper boss 21. Each of the bosses is provided with a plurality of radially-extending openings 23, such as the four equally-spaced openings shown in the drawings, whereby when the bosses are telescoped with one another, a cotter pin or key 24 may be passed through the alined openings of the two bosses to join two of the housings 18 together. The provision of a plurality of the openings 23 permits rotational adjustment of successive charge housings so that all the charges may fire in one direction, each successive charge may fire in a direction displaced 90° from the charge thereabove, or 180° from the charge thereabove, or any other suitable or desirable arrangement. In most instances, each succeeding charge will be displaced 90° from the charge thereabove so as to obtain a uniform and properly spaced pattern of perforations.

Each of the housings 18 is provided with a cylindrical bore 25 within which the cylindrical charge 26 has a snug sliding fit, and terminates adjacent the head 19 in a shoulder 27 against which the charge may seat. The inner wall of the head 19 is, of course, dished to conform to the convex outer wall of the head and be spaced from the explosive charge. The cap 20 has an annulus 28 cut away on its inner face and near its periphery to form a marginal flange 29 which has a press fit in the outer end of the bore 25. In addition, a flange 30 is provided on the cap 20 for abutting the open end of the housing 18, and the latter may be chamfered, as shown at 31, so as to receive a sealing O-ring 32 which is distorted by the flange 30 into sealing position and thus assures watertight integrity for the interior of the housings 18.

The cap 20 also is provided with a central recess 33 on its inner face for receiving a booster charge 34, the recess 33 extending very closely to the outer face of the cap 20 so that only a very thin wall 35 is present between the booster charge 34 and the firing cord 17. As shown in FIG. 1, the firing cord is spiraled around the assembly of perforating charges approximately in a helix, a portion of the cord passing over the center portion of each of the caps 20 and being held in snug engagement with the end wall section 35 by means of an overlying clip 36. Thus, when the firing cord 17 is detonated, its explosive wave or force will almost instantaneously perforate or burn through the thin wall section 35 for substantially simultaneous detonation of all of the booster charges 34.

These jet perforation assemblies 16 are of the self-destroying type and desirably are formed of a suitable cast aluminum alloy, or other of the various well-known alloys which are readily drillable, will readily break or fracture under explosive forces, and which need have only sufficient strength as to withstand the hydrostatic head or pressure to which they are subjected in the well bore. The housing 18 can be relatively thin walled in nature, and the plugs 20, likewise, need only be of sufficient massiveness as to insure proper assembly of the perforating structure and water-tightness thereof. To aid in the disintegration, or possible subsequent drilling up of the plugs 20, they may be weakened by a plurality of recesses 37 formed in the outer faces of the plugs.

The explosive charges 26 are desirably housed in a thin-walled metallic shell or tube 38 for ease in handling and positioning within the bores 25 of the housings 18. Insofar as the perforating results which are obtained, however, the shell 38 is of little importance except that it must be of such nature as to fracture or break up readily upon occurrence of the explosion, and any fragments which remain should be readily drillable from the well bore. The rearward portion of the sleeve 38 is filled with a suitable explosive material 39, to be discussed hereinafter, which extends forwardly against a liner 40 of V-shaped cross-section. As shown in FIGS. 3 and 4, the liner is relatively thin and has its apex 41 directed rearwardly toward the plug 20 when it is positioned within the housing 18. Each leaf or wing 42 of the liner is semi-elliptical in form, the two wings joining at an angle of approximately 90°, and the semi-elliptical shape of the wings resulting in the entire perimeter or periphery of the liner engaging the inner wall of the shell 38. Thus, the liner completely encloses the forward portion of the explosive charge 39, and the forwardmost edges 43 of the liner terminate at or near the forwardmost edge of the shell 38 which, as previously pointed out, abuts the shoulder 27. The rearward face or part of each of the charges 26 is flat so as to be snugly abutted by the inner face of the plugs 20, the flanges 29 engaging the rearward edge of the sleeves 38 to hold the same in snug engagement with the shoulders 27, and the recesses 33, containing the booster charges 34, being brought into contiguity with the rearward face of the explosive charge 39. Thus, the detonation of the booster charges 34 results in the virtually instantaneous detonation of the jet perforation charges 39.

A jet perforator charge of the configuration illustrated and described will cut a slot in a well pipe rather than a circular opening, such as has been conventional practice, and the general outline of a typical perforation obtained by this charge is shown in FIGS. 5 and 6. The charge assembly 16 is indicated in dotted lines in FIG. 5, and as shown, a slot 44 will be cut through the inner casing 45, the cement or concrete bedding 46 for the casing, the second well pipe or casing 47, and into the formation 48. As shown in FIG. 6, the slot 44 is of the general shape of a flattened ellipse, a typical penetration for a charge 2 inches in diameter being the formation of a slot approximately 3 inches long and ¾ of an inch wide at its widest point. Necessarily, the slot will decrease in length and width as it is traced into the formation, the slot formed in the second pipe or casing 47 in the above instance being approximately 2 inches long and ½ inch wide at its widest point. For best results, it is, of course, important that the perforator assemblies 16 be spaced slightly from the well pipe, the most desirable spacing having been found to be from ½ to 1 inch diameter of the charge 26, this, in the case of a 2 inch diameter charge, being from 1 to 2 inches. This spacing is not critical or absolutely essential, but in general, is obtained without difficulty and more or less automatically when a shot assembly string, as illustrated in FIG. 1, is lowered into a well casing which is of somewhat larger diameter than said assembly.

The charge illustrated will cut a slot having its longitudinal axis alined with the apex 41 of the liner 40, and due to the cylindrical configuration of the charge 26, it is obvious that longitudinal axis of the resulting slot may be oriented in any desired direction. In most instances, it is preferred that the slots be cut parallel to the longitudinal axis of the well pipe, but various degrees of angularity are readily obtained simply by revolving the charges 26 within the housings 18, or slots at a varying number of angles may be obtained by suitable revolving of the individual charges within the individual housings 18. Further, it is to be noted that the detonation of the charge 39 is instituted in the geometrical center of the rearward portion of the charge and in alinement with the apex 41. This is important for obtaining uniform and proper detonation and for maintaining the desired degree of directionality of the resulting, slot-cutting jet.

The booster charges 34 and the jet forming charges 39 may be formed of any suitable or desirable explosive material, such as those enumerated hereinabove for use in the firing cords 17. In general, of course, the booster charge is formed of an explosive more sensitive to shock than the charge 39, and more readily capable of being detonated by the firing cord 17, and in turn, to function to detonate the main charge 39.

A charge 2 inches in diameter has been found most suitable for general oil field use in that satisfactory perforation of the well casing is obtained, and such a charge is quite capable of handling the various sizes of casings most commonly encountered. The charge should consist of from 50 to 100 grams of explosive compacted under pressure within the sleeve 38 to a specific gravity of 1.5 to 1.6. An acceptable slot is obtained when 50 grams of explosive is employed, but it is preferred to employ 65 to 75 grams of explosive in order to obtain a relatively narrow and quite deep slot and perforation. Above 75 to 100 grams of explosive does not produce any appreciable increase in the depth of penetration, but does add to the total quantity of explosive being detonated in the well bore and hence becomes objectionable. Since all of the perforating charges detonate substantially simultaneously, their combined weights of explosive must be considered as the quantity of explosive being discharged, and this value must be kept below certain limits in order to avoid damage to the well pipe or to the cement in which it is embedded. Accordingly, it may be stated that the charge in each of the assemblies 16 should not exceed 75 to 100 grams nor be less than 65 to 70 grams. As before stated 65 to 75 grams of explosive produces optimum results and is much to be preferred. Similarly, although the explosive may be compacted to a specific gravity of 1.5, a gravity of 1.6 is preferred and results in better performance and penetration by the charges.

The diameter of the shells 38 and hence, of the charges 26, necessarily becomes critical in conjunction with the weights of explosive charges given hereinabove. The charge diameter should be from 1¾ inches to 2¼ inches for consistent obtaining of a 3 inch slot in the pipe 45, it being pointed out that smaller diameter charges do not have the universal adaptability and application of a charge of the size specified, and larger charges tend to involve too much explosive and to cut a slot of too great width. This, then, is an instance in which the dimension of the charge as well as its configuration becomes of importance.

The liner 40 may be formed of zinc, tin, aluminum, or nickel, but preferably and most desirably is formed of copper or brass. The liner 40 must be between 0.040 and 0.080 of an inch thick, with 0.055 to 0.065 of an inch being preferred and furnishing the best penetration results. Below 0.040 of an inch, sufficient penetration is not always obtained, and the slot tends to become wider. Above 0.080 of an inch thickness for the liner 40, penetration also starts to diminish and the slot 44 may narrow excessively. Thus, the liner preferably is formed of copper or brass and must be between 0.040 and 0.080 of an inch thick.

The angularity of the apex 41, or the included angle between the faces 42, is also critical and must be from 85° to 95°. 90° is preferred, but as much as 5° variation may be tolerated without excessive loss of performance. It is also essential that the apex 41 be properly centered or alined with the central axis of the charge 39, the maximum tolerance of misalinement being 0.015 of an inch. As thinner liners are used, such as liners of 0.040 of an inch thick, the criticality of misalinement becomes more pronounced and should not exceed a maximum of 0.010 of an inch.

The jet perforating assembly which has been shown and described is inexpensive to manufacture and assemble, and readily lends itself to widely varying conditions of use in the cutting of slots in the walls of a well pipe at any suitable or desired angle. The structure is of sufficient strength and watertight integrity as to withstand the hydrostatic pressure encountered under operational conditions, but, at the same time, is of such nature as to be virtually self-destroying, any fragments of a detonating assembly remaining in the well being readily drillable from the well bore with conventional equipment. The various limitations and dimensions which have been recited were determined empirically since no method of calculation of these critical factors and limits is known to exist.

The combination of a cylindrical charge having an angular liner and cavity is unique and permits wide variation in the operation of the gun although in most instances, it will be desired to cut slots in a well pipe parallel to the axis of the pipe. Further, the specific ranges of weights, dimensions, density, alinement, thicknesses, and angles, which have been enumerated, have all been found critical and important for effective operation of the charges, and it has been established that variation outside of those ranges and limits which have been given result in unsatisfactory performance and an unreliable jet perforating charge.

The foregoing description of the invention is explanatory thereof and various changes in the size, shape and materials, as well as in the details of the illustrated construction may be made, within the scope of the appended claims, without departing from the spirit of the invention.

What we claim and desire to secure by Letters Patent is:

1. A jet perforating charge for well pipe comprising a cylindrical body of an explosive having a recess defined by two plane faces at one end thereof with the recess faces forming a dihedral angle, with the apex line of the dihedral angle substantially intersecting the central axis of said body at right angles thereto, a detonator at the end of said body opposite said recess and aligned with the body central axis, and a housing containing the body of explosive.

2. A jet perforating charge as set forth in claim 1, and a metallic liner in the recess and conforming thereto.

3. A jet perforating charge as set forth in claim 2 wherein said dihedral angle is within the range of 85° to 95°.

4. A jet perforating charge as set forth in claim 3 wherein the thickness of said liner is within the range of 0.04 to 0.08 inch.

5. A jet perforating charge for well pipe comprising a body of an explosive having a central longitudinal axis, a front face, and a rear face, with said front face having a recess defined by two plane faces forming in said body a dihedral angle, with the line of the dihedral angle apex perpendicular to and substantially intersecting said central axis, and with each said plane face having the shape of a minor segment of an ellipse with the axis of symmetry of said segment normal to and bisecting said apex line, a detonator adjacent the rear face of said body and aligned with said central longitudinal axis, and a housing containing said body.

6. A jet perforating charge as set forth in claim 5, and a metallic liner in the recess and conforming thereto.

7. A jet perforating charge as set forth in claim 6 wherein said dihedral angle is within the range of 85° to 95°.

8. A jet perforating charge as set forth in claim 6 wherein the thickness of said liner is within the range of 0.04 to 0.08 inch.

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