May 6, 1958 J. J. UDRY 2,833,213

WELL PERFORATOR

Filed April 13, 1951

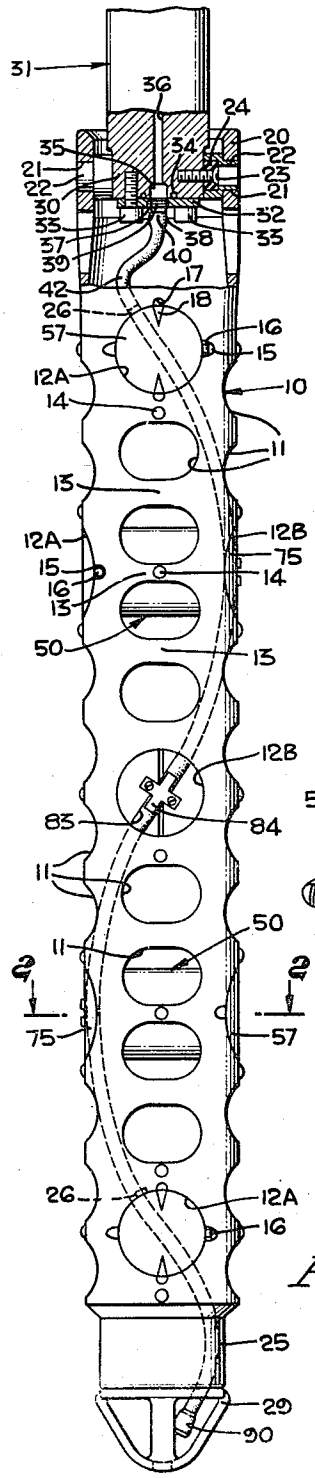


FIG. 1.

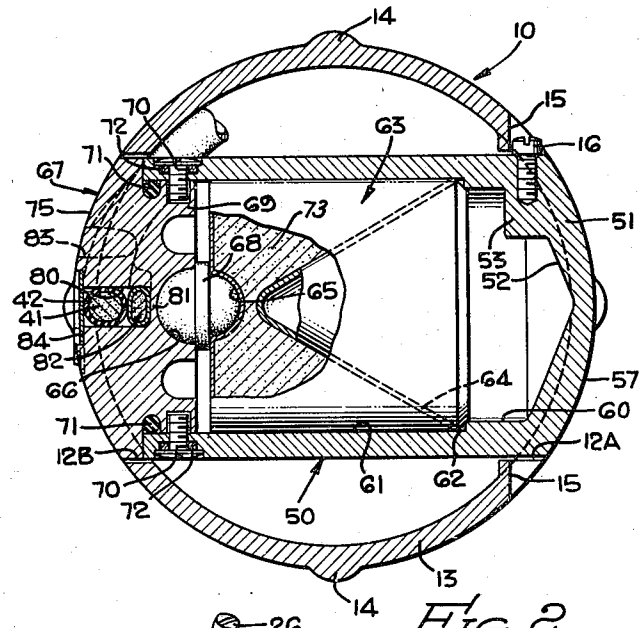


FIG. 2.

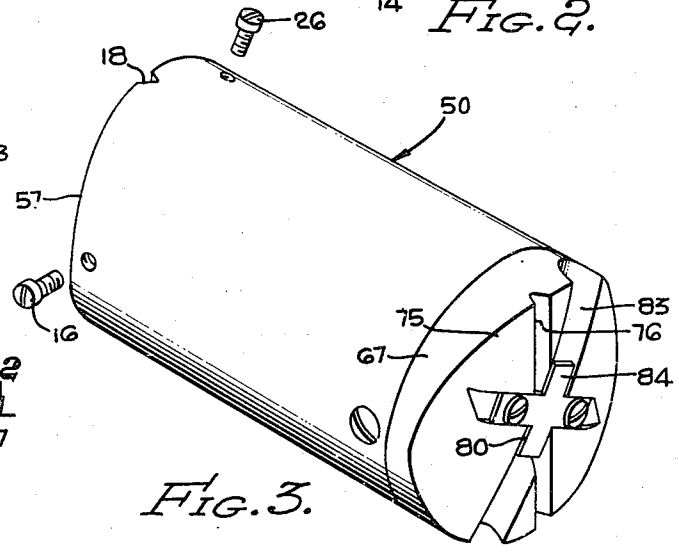


FIG. 3.

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WELL PERFORATOR

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Application April 13, 1951, Serial No. 220,770

4 Claims. (Cl. 102—20)

This invention relates generally to well borehole perforation, and more particularly to apparatus utilizing explosive force for penetrating the formations surrounding a well borehole for the purpose of facilitating the flow of well fluid into the well.

In the past it has been frequent practice, in oil well completion operations, to subject a formation within the depths of a well borehole, at the zone where fluid entrance is desired, to the action of an explosive charge to open up flow channels and increase the apparent or effective permeability of the formation at such predetermined location. Such early practice was known as "well shooting" and included the discharge of a quantity of dynamite or nitroglycerine within the wellbore at such zone.

More recently, perforation of the formation has been accomplished by firing bullets from a special gun device to pierce the formation at the chosen zone. In the use of bullets for this purpose, it has been the usual practice to discharge them from within the casing disposed within the wellbore and thus simultaneously to perforate the casing and surrounding formations to facilitate flow of well fluid from the pierced formation to the interior of the casing. The original method of blasting the borehole formation or "shooting the well" with the undirected force of nitroglycerine or the like explosive was then, to some extent, superseded by the bullet-piercing method, the action and penetration of which could to some extent be directed and controlled.

One of the latest developments in formation piercing and casing perforating has been the use of "shaped charges" of high explosive material. Such charges are usually formed with a conical discharge face from which, upon detonation, a high velocity jet is projected with sufficient force to penetrate the well formation. Such charges have been found well suited for perforating well casing as well as piercing the surrounding well borehole formation. Therefore it is today common practice to lower a shaped charge perforating device into the wellbore or casing, each device having mounted therein a plurality of laterally directed shaped charge units from which, upon firing thereof, penetrating jets are projected in different radial directions into the surrounding formations.

The use of the combined blasting and piercing effect of shaped charges has been found preferable in many cases to the use of either a bullet perforator or an ordinary explosive shooting charge alone, particularly in an uncased portion of a well borehole, from which production is desired.

Shaped charge perforating guns heretofore available were heavy, costly, expensive, and not particularly well suited to open-hole shooting. Such guns generally consisted of closed, retrievable body members in which were mounted the shaped charges in registration with suitable firing ports through which substantially only the force of the shaped charge jets issued. The surrounding casing or formations were thus largely shielded from the

undirected portion of the shaped charge blast. Retrievability of such guns was achieved by virtue of the use of expensive, high strength materials and costly designs as a result of which a limited reloading and reuse of the gun was possible. Nevertheless, the lives of such guns were quite limited, since repeated firing subjects the gun to progressive deformation and weakening and causes mutilation of the discharge ports. A further difficulty with such guns was the necessity of securely sealing the interior thereof against ingress of well fluid which is frequently present at considerable pressure at the zone in the well borehole to be perforated. Such sealing cannot be accomplished economically, nor will presently known means for accomplishing it withstand indefinite firings of the gun.

It is, therefore, a principal object of the present invention to entirely avoid, or greatly minimize, the difficulties and disadvantages of prior apparatus which employed shaped charges in retrievable perforating guns.

Another object of this invention is to provide an improved "well shooting" device.

Another object is to devise ways and means to utilize shaped charges without sealing the shaped charge container body as a whole against entrance of well fluid.

Another object is to provide an economical, expendable shaped charge carrier.

A further object is to provide a separable, self-contained and sealed shaped charge unit for use in casing and formation perforating apparatus.

It is also one of the objects to provide novel and improved means of detonating a shaped charge mounted within a closed carrying case.

The objects of the present invention are accomplished in general by providing a carrier for several shaped charge units adapted to be lowered into a well borehole, which carrier comprises an elongated, frangible, open member formed of brittle material such as cast iron or the like material, which will, in response to the shock of the detonation of the shaped charge units, substantially disintegrate, forming particles and fragments of such size and character as to fall to the bottom of the borehole, and either remain there without interfering with subsequent operations or be capable of being readily removed by subsequent bailing operations. In order to maintain the weight of the device at a minimum and to facilitate the desired fracture, fragmentation, and disintegration thereof, the carrier is formed with relatively thin walls and with a plurality of relatively closely spaced openings or holes therein so that the body constitutes, in effect, a relatively, light, fragile, open network of supporting material. Special openings of suitable size and shape are also formed in the carrier body at diametrically opposite points, through which the individual shaped charge unit containers extend and are supported. The device is further characterized by end constructions by which it may be readily secured to a firing head and, if desired, coupled end-to-end to other similar gun bodies.

Each of the before-mentioned shaped charge units comprises a suitable explosive shaped charge container within a close-fitting, fluid-tight housing. As here shown, each shaped charge housing comprises a hollow, substantially cylindrical, sealed container made of frangible material, such as cast iron or the like material. The rear end of the housing is formed with an external fuse channel and detonator charge recess. Within the rear end of the housing is a companion internal detonator container recess, there being formed a thin firing wall between the said internal and external detonator recesses. The housing is suitably sealed to exclude well fluid, and coaxial within the housing and mounted to face the forward end closure thereof, and positioned with proper stand-off distance therefrom, is the explosive shaped

charge. As will be further apparent from consideration of the following specification, detonation of the shaped charges ruptures and disintegrates the whole of the carrier as well as the individual shaped charge housing units.

While the material, such as cast iron, of the individual casings, as well as the gun body, is readily fractured and disintegrated by the explosive force of the charge, it will also be noted that such material is readily obtained and inexpensive and that the present construction is such that a minimum of shaping, machining, or working of the casting is required, the gun bodies as well as the charge housings thus being expendable without incurring prohibitive well shooting expense. It will further be noted that the present device is simple and readily designed for assembly at the place of use without special skill or tools. This feature also permits the manufacture and transportation of the charge units independently of the carrier so as to minimize hazard in such transportation.

Other objects, advantages, and features of novelty will be evident hereinafter in the more detailed description of the invention.

In the drawings, which illustrate a preferred embodiment of the invention, and in which like reference characters designate the same or similar parts throughout the several views:

Figure 1 is an elevational view of a complete gun carrier assembly with the charge units in position, parts being broken away to illustrate certain features;

Figure 2 is a transverse sectional view through the gun assembly taken on the line 2—2 of Figure 1; and

Figure 3 is a perspective view of the charge unit.

In the drawings, **10** is the shaped charge unit carrier, which is formed as a thin, perforate, open, cylindrical shell, preferably made of a frangible or brittle material such as, for example, cast iron. As indicated at **11**, the walls of the shell are weakened and the shell is lightened by a plurality of substantially uniformly spaced openings, here shown as oval in shape. The charge unit carrier or shell **10** is also provided with a plurality of pairs of diametrically opposite shaped charge unit receiving and mounting openings, opposite openings of each pair being shown respectively at **12A** and **12B**. The opening **12A** of each pair serves as the discharge opening supporting the forward end, while the opening **12B** serves as the rear fuse end opening supporting the rear end of the shaped charge unit hereinafter more fully described. In the arrangement here presented by way of illustration, the openings **11** are disposed in longitudinal rows aligned with the charge unit openings **12A** and **12B**. Four such openings **11** are here shown between each parallel pair of charge unit mounting openings **12A** and **12B**, although different numbers of different sized holes may be employed. The carrier body **10** in the present form of the invention is disclosed as having five pairs of charge unit mounting openings **12A** and **12B**, although any desired number may be employed by suitably modifying the longitudinal dimensions of the carrier. The several pairs of mounting openings are arranged in different positions along the length of the carrier **10**. In the arrangement illustrated, it will be seen that in assembling the charge units in their mounting openings the top unit may face in one given lateral direction, the second, lower unit may be disposed to face in a lateral direction ninety degrees from the direction of the top charge unit, the lower, third unit may be mounted to face diametrically opposite to the direction of the top charge unit and thus at ninety degrees from the angular disposition of the second charge unit, and so on, each adjacent charge unit being faced at a horizontal angle ninety degrees from that of its adjacent charge unit.

In considering the size, shape, and disposition of the openings **11**, **12A**, and **12B** of the carrier body **10** here illustrated, it will, of course, be understood that such size, shape, and disposition are merely by way of illustration and that the invention is in no way limited or confined to the exact arrangement shown. It is generally customary in perforating guns of either the bullet type or the shaped charge type to arrange the structure so that a spiral pattern of perforations will result from the firing of all of the charges, and such arrangement is adhered to in the structure hereinbefore described. However, the charges may all be mounted parallel with one another or in any other angular position suited to the service to be performed. The invention is not limited or restricted to the number or spacing of the charge units here shown, since, as before mentioned, a single unit or any desired number of units may be mounted in a single carrier body.

Extending from some of the webs **13** formed between certain of the openings are wear and contact buttons, as shown at **14**, which serve to space the body slightly from the wellbore or casing as it is lowered or raised therein to prevent undesirable scraping therebetween. The peripheries of the discharge openings **12A** are suitably recessed, as shown at **15**, to receive in locking engagement aligning screws **16** which are threaded into the shaped charge housings adjacent the discharge ends thereof. The same shaped charge unit openings of each pair of openings are also provided with diametrically opposite notches **17** which register with diametral marking and fracture weakening grooves **18** on the forward end faces of the charge unit housings so as to facilitate orientation of each of the units within its pair of mounting openings.

The upper end of the gun or carrier body **10** is formed with a hollow cylindrical sleeve portion **20** having a pair of diametrically opposite openings **21** through which and between which securing means such as the adapter bosses **22**, attachment screw **23**, and carrier washer **24** may be fitted. The opposite, lower end of the carrier body **10** terminates in a hollow, cylindrical sleeve portion **25** of reduced diameter. While the present drawings do not illustrate the end-to-end interconnection of a plurality of carrier bodies **10** to constitute a single elongated carrier assembly for supporting a multiplicity of the charge units, such is here contemplated. It will be noted that the internal diameter of the upper coupling sleeve **20** is approximately equal to or slightly greater than the external diameter of the lower coupling sleeve **25** so that a plurality of such carrier bodies may be telescopically joined end-to-end by the insertion of the lower sleeve **25** of one body within the upper sleeve **20** of a next adjacent carrier body, whereupon secure joining of such bodies may be accomplished by the use of appropriate securing screws.

In the illustrative form of the invention here shown, the upper coupling sleeve portion **20** of the carrier body **10** receives therein the reduced lower end **30** of a firing head **31** to which it is secured by the before-mentioned screws **23**. The present invention is, of course, not limited to any particular method or apparatus for the detonation of the shaped charges mounted within the body; however, one preferred form of firing head is here fragmentarily illustrated. At the lower end of the head **31** within the body **10**, an apertured plate **32** is secured centrally to the head **31** by bolts **33** and sealed by an O ring **34**. The central aperture **35** of the plate **32** communicates with a central passage **36** in the firing head **31** and is sealed prior to firing by a relatively thin disk **37** press-fitted within a counterbore **38** facing outwardly or downwardly from the head **31**. Mounted within the counterbore **38** and seated against the lower surface of the disk **37** is a mushroom-headed detonator **39**, to the neck **40** of which is secured the end of the fuse **41** for detonating the shaped charges, as will be hereinafter described. The fuse **41** is preferably of an explosive or detonating type such as, for example, that referred to commercially as "P. E. T. N. Plastic Covered Primacord," designated as "100 gr/ft." The fuse **41** is covered throughout its length by a rubber tubing **42** which fits, at its upper end, tightly over the downwardly projecting neck **40** of the detonator **39**. A detonating charge or cap of conventional type (not shown) is mounted within the body of the detonator **39**, which

rests in contact with the outer, lower face of the disk 37. With such assembly it will be apparent that, when the charge within the detonator 39 is fired, the fuse 41 will therby also be detonated. Various well known means may be employed for firing the detonator 39, and therefore no specific means are here shown. Suffice it, therefore, to point out that the detonator may be made percussion-responsive, so that a blow by a firing pin thrust down through the passage 36 against the upper face of the disk 37 will serve to discharge the detonator, or the detonator may be fired by conventional electrical means if preferred.

As hereinbefore indicated, the shaped charge units are mounted within the carrier body by seating them crosswise through the opposite openings 12A and 12B. Each shaped charge unit comprises a hollow, cylindrical housing 50 closed at its forward or discharge end by an integral forward end wall 51 having an internal surface 52 of conical form. A pair of circumferentially spaced bosses, one of which is shown at 53, extend inwardly from the conical inner surface 52 to accommodate the inner ends of the aligning screws 16. The outer surface of the forward end wall 51 is curved with respect to a longitudinally extending transverse plane through the body, as indicated at 57, so that, when the housing is properly oriented within the opening 12A, the outer end surface thereof will form a flush continuation of the cylindrical outer wall surface of the gun body.

The interior of the shaped charge housing is substantially cylindrical in form, having a portion of reduced inside diameter adjacent the forward or discharge end, as indicated at 60, and having a larger bore 61 rearward thereof, forming at the juncture thereof an annular shoulder thereof, forming at the juncture thereof an annular shoulder 62. Normally contained within the hollow chamber or housing thus formed, is the shaped charge, as indicated at 63, having the characteristic concave, conical front or discharge face 64 directed coaxially of the charge housing axis and toward the center of the forward end wall 51. As shown, the conical discharge end of the charge 63 is seated against the shoulder 62. The body 73 of the shaped charge 63 may be composed of any of the well known high explosives suitable for the purpose, such as, for example, pentaerythritol tetranitrate and the like. The diameter of the exterior, cylindrical surface of the explosive charge should be such as to make a close but free fit within the beforementioned intermediate bore 61 of the housing 50, and should be formed with a forwardly facing concavity, preferably conical in shape and lined with a conical metal lining, as shown at 64. The balance of the exterior surface of the charge may be covered by a suitable layer of tin or aluminum sheet or foil. For further general considerations of shaped charge construction and characteristics, reference may be had to the prior art, for example, Davis and Burrows No. 2,399,211 and Muskat et al. No. 2,494,256.

The rear face of the charge 63 is here shown as formed with a centrally disposed, hemispherical recess 65 cooperating with an oppositely facing hemispherical recess 66 formed in the rear end closure 67 for the housing 50. The recesses 65 and 66 form, in part, a chamber for the reception of an auxiliary detonating charge, indicated at 68, which controls the firing of the shaped charge 63. The rear end closure 67 has a short cylindrical body portion 69 of reduced diameter adapted to fit within the rear end of the housing 50 and to be secured therein by screws 70. An O ring 71 is mounted in a suitable annular groove between the housing and end closure to seal the same against ingress of well fluid, and O rings 72 are also mounted in suitable annular grooves around the screws 70 to seal their openings in a similar manner.

The outer face 75 of the end closure 67 is curved as indicated, similar to the before-mentioned curvature of the forward face of the discharge end of the housing, to conform with the cylindrical exterior surface of the carrier body 10. The end closure is provided with a transverse weakening notch 76 which is disposed vertically when the housing is properly oriented. The outer surface of the end closure 67 is also formed with an external recess 80 in registration with the internal hemispherical recess 66 and forming a relatively thin, frangible wall 81 therebetween. Seated within the external recess 80 is a so-called booster charge 82. The end face of the closure is further provided with a transversely extending fuse channel or groove 83 which traverses the booster charge recess 80. The fuse cord 42 is mounted to extend from the main detonator 39 at the upper, inside end of the carrier body, and to extend downwardly and outwardly over each of the end closures 67 and through each of the channels or grooves 83 overlying the booster charges 82, and is clipped in close contact with each booster charge end closure by means of securing members 84. With this arrangement, it will be seen that in operation, as the fuse detonates, the underlying booster charges 82 of the successive charge units will be substantially simultaneously ignited, and, upon firing thereof, the heat and/or impact will penetrate the thin walls 81 and substantially simultaneously fire the auxiliary detonating charges 68 and thereby in turn detonate the shaped charges 63.

From a consideration of the foregoing structure, it will be seen that the shaped charge units may be manufactured and assembled independently of the gun body. Such units may be of varying size and shape and may be supplied to the user in such number, size, and power as required. Assembly of the charge units in the gun may thus be made at the point of use, where the fuse may be applied, so as to avoid transportation of the combined units and detonators. The units are assembled in the gun by insertion of the rear or firing end of the housing, with its closure cap 67, through the opening 12A of the gun body and thereafter seating the firing end in the opposite opening 12B of the body. In addition to the aligning screw 16, the firing end of the housing is provided with a screw 26 which protrudes therefrom and passes through notch 17 and engages the inside surface of the wall of the carrier body after the housing is rotated slightly about its axis sufficient to align the threaded hole for the screw 16 with the recess 15. After proper orientation of the unit in this manner to bring its end curvatures into conformity with the curvature of the body surface, the units are secured in position by insertion of the screw 16 into its threaded hole in the housing, which locks the unit housing against further movement, either rotationally or in either direction longitudinally. The fuse is then attached to the firing head and extended within the body to the first unit, where it passes outwardly into the groove 83 and across the outer face of the end closure and over the booster charge 82, with which it is secured to the end by the clips 84, and so on throughout the several charge units. When a bull plug 29 is secured to the lower end of the gun body, as in Fig. 1, the end of the tubing covering the fuse is sealed fluid-tight by a suitable plug 90. If, however, one or more additional gun bodies are connected end-to-end, the fuse is extended, in required length, into the second gun body. Separate fuses for each body may be employed if desired, in which case the separate fuses may be joined or coupled together, preferably through a suitable coupling containing a booster charge and suitable fluid-tight covering means to insure ignition of the second fuse from the first.

In operation, with the gun completely assembled in the manner set forth, the charge units in position, the fuse and booster charges in place, and the firing head in position, the assembly is lowered, upon suitable tubing or conductor cables as the case requires, into the wellbore or well casing to the zone at which perforation or formation piercing is desired. After location in such position, the primary detonating charge may be fired through such firing mechanism as may be selected, and the fuse 42 is thereby detonated. The resultant detonation of the fuse detonates the external booster charges in the end closures

of the unit, which in turn detonate the internal auxiliary detonators and the shaped charges. Upon firing of the shaped charges, the resultant penetrating jets projected radially outward coaxial with the axis of the shaped charge **63** and the cone **64** pierce the surrounding borehole wall and adjacent formations. While the initial and major forces of the discharge of the shaped charges contained in the carrier are directed axially of the shaped charges and of the housings in the form of penetrating jets, it will be understood that such jets are by no means the only forces generated by such discharge. The accompanying secondary explosive forces radiate generally in all directions from the shaped charge, and thus the frangible housings and their end closures are instantly shattered and disintegrated by the force of such explosion, followed by shattering and disintegration of the entire carrier body, leaving nothing but small particles or fragments which may fall harmlessly to the bottom of the wellbore or casing. Not only does such explosive force have the desired result of shattering the carrier body and charge housings, but, when employed in an uncased, open hole, the fragments of the shattered carrier and housings perform a general scouring of the borehole wall to remove the relatively impervious glazing and mud cake therefrom and otherwise promote fluid flow from the surrounding formation.

In connection with the discharge of the shaped charges, it should be noted that the type of fuse employed, such as the "Primacord" hereinbefore mentioned by way of example, is selected mainly because of its extremely rapid action, which is such as to exceed the speed of the transfer of the shock wave from charge to charge resulting from the discharge of the units. Thus, while the explosive force of the discharge of a single one of the several units might be such as to cause the sympathetic discharge or the interference of the discharge of a companion unit or several companion units, all of the units, if properly spaced, will have been fired by the fuse before such sympathetic discharge can take place. Thus, the required and proper firing of each of the shaped charges is insured. This type of fuse is also chosen because its sensitivity is sufficiently low to render it safe from accidental detonation by any ordinary shock or blow. Preferably, the detonator charge in the detonator **39**, the booster charge **82**, and the auxiliary charge **68** are also composed of a relatively insensitive high explosive material, which may be the same material as that of which the "Primacord" fuse or the body of the shaped charge is made; or they may be made of "R. D. X.," which is the trade name of an explosive material which is manufactured by E. I. du Pont de Nemours and Company. The shaped charge itself may also be made of R. D. X. with satisfactory results. Assembly of the selected shaped charge units in the carrier, together with their fuse and booster and auxiliary charges, at the factory or any desired point of assembly is permissible, and thus transportation of the fully assembled and loaded perforating devices from such point of assembly to any desired point of use is practicable.

From the foregoing it will be seen that numerous advantages are achieved by the use of light and inexpensive material, such as the cast iron suggested. Economy of manufacture and efficiency and safety in use are attained by eliminating from the final and complete apparatus assembly any and all explosive components and materials which are classified in the explosive industry as "sensitive." Since the whole gun, including charge unit housings, is disintegrated and wholly shattered by the explosive force, retrieving and/or fishing of fragments from the wellbore or casing is not usually necessary after use.

While one preferred embodiment of the general inventive concept is here shown, it will be understood that the invention is not limited or restricted to these exact structural features. The carrier body may be of different size and shape, and the number, arrangement, and spacing of the charge units may be varied, if desired. Nor is the invention confined to the use of a frangible and expendable carrier body, since the charge units and housings herein disclosed constitute independently novel devices which may find usefulness in other types of carriers.

Thus it will be understood that the present invention may be practiced with numerous changes and modifications obvious to those skilled in the art and the full use of equivalents may be resorted to without departure from the scope of the invention as defined in the appended claims.

What is claimed is:

1. Expendable well shooting apparatus comprising: an elongated, hollow, cylindrical carrier body formed of brittle material, the walls of said body having formed therethrough a plurality of lightening and weakening openings adjacent one another throughout the length and circumference thereof and a plurality of pairs of shaped charge unit supporting apertures; shaped charge units being mounted within said cylindrical body through said supporting apertures, each such unit comprising a hollow, cylindrical, fluid-tight housing formed of frangible material, means for mounting a shaped charge therein, a shaped charge mounted in said housing, the ends of the shaped charge units being curved to conform with the curvature of the cylindrical external surface of said carrier body and being substantially flush with said external surface, one end of each shaped charge unit having a detonating fuse receiving groove opening into the outer face of said one end and extending substantially diametrically thereacross, the depth of each said groove being substantially greater than the thickness of the walls of said body and the ends of said groove opening into the hollow portion of said carrier body; a detonating fuse disposed in the hollow portion of said carrier body and extending through the groove in the said one end of each shaped charge unit in detonating relation to the shaped charge in each unit housing; and means to detonate said fuse.

2. Expendable well shooting apparatus as defined in claim 1 including in each shaped charge unit means for retaining the detonating fuse in the groove comprising a fuse securing member overlying the fuse and means mounting said securing member to said one end of the shaped charge unit substantially flush with said one end.

3. Expendable well shooting apparatus as defined in claim 2 in which the material forming said carrier body and the material forming the housing of each shaped charge unit is cast iron.

4. Expendable well shooting apparatus as defined in claim 1 comprising a plurality of wear and contact buttons extending outwardly from said cylindrical carrier body.

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 2,833,213 May 6, 1958

John J. Udry

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

Column 5, lines 32 and 33, strike out "thereof, forming at the juncture thereof an annular shoulder".

Signed and sealed this 16th day of December 1958.

(SEAL)
Attest:

KARL H. AXLINE
Attesting Officer

ROBERT C. WATSON
Commissioner of Patents

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