United States Patent

Bauer

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[54] **ECONOMICAL, TOUGH, DEBRIS-FREE SHAPED CHARGE DEVICE AND PERFORATING GUN ASSEMBLY EMPLOYING SAME**

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[51] **Int. Cl.** **F42b 3/08**

[58] **Field of Search** 175/4.6; 102/20

[56] **References Cited**

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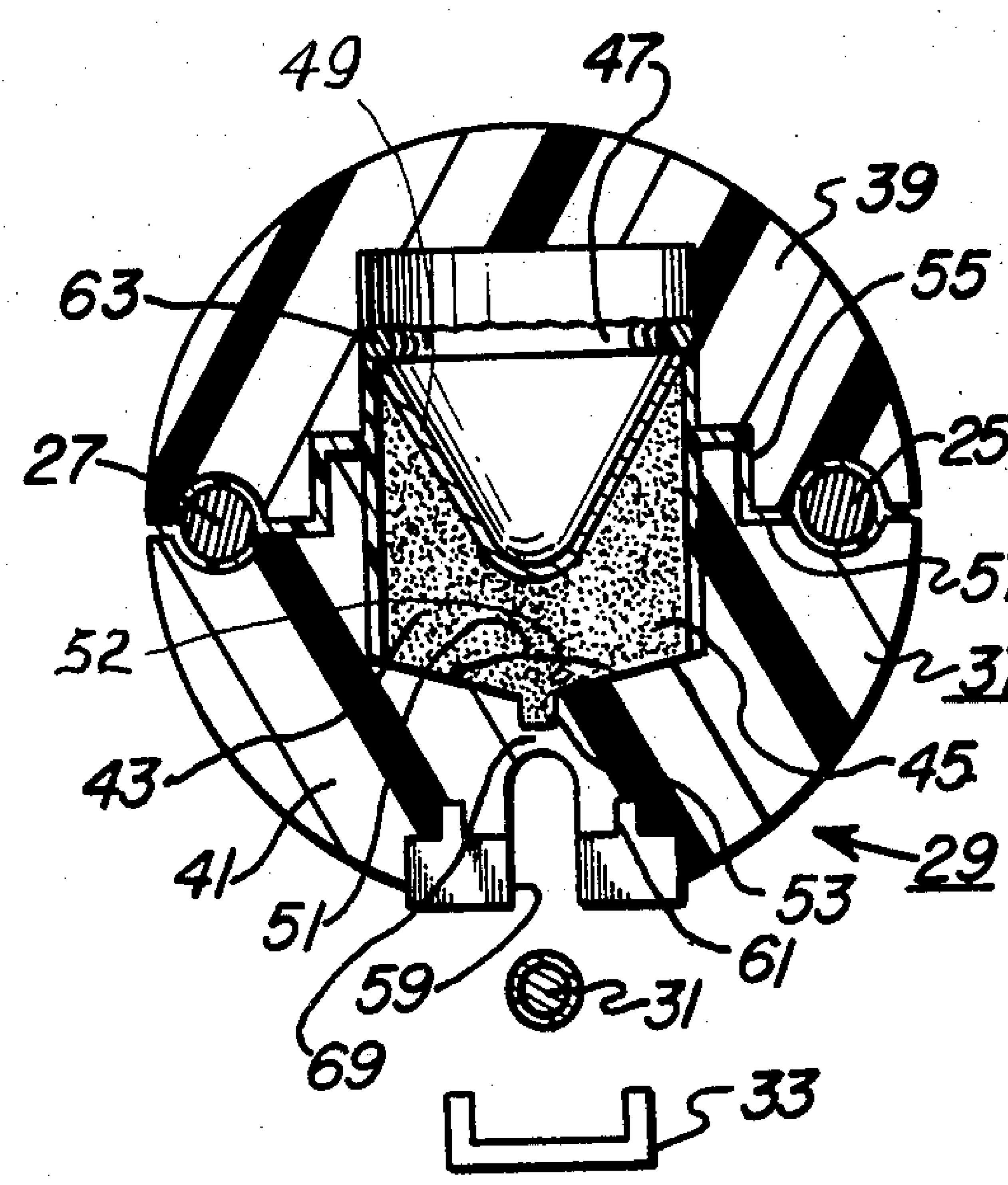
[57] **ABSTRACT**

A shaped charge device, and perforating gun assembly employing same, characterized by an economical case made of a thermosetting plastic containing a critical proportion of macerated material to induce a strength and toughness that enables resisting temperature, pressure, and impact deformation and breakage and invasion of fluids under conditions of use to depths in excess of 10,000 feet; yet that will disintegrate into small particles upon detonation, leaving no harmful debris in a well being perforated. Through the use of the plastic containing the critical proportion of macerated material, thicker case walls may be employed yet still obtain detonation therethrough. The critical thickness of walls adjoining a detonation means, and preferred construction features, plastics, and macerated materials are also disclosed.

17 Claims, 4 Drawing Figures



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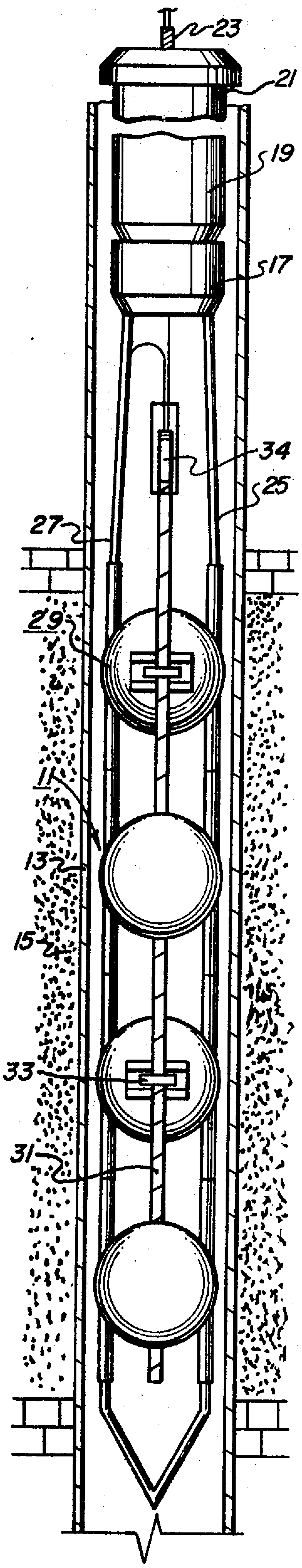

Fig. 1

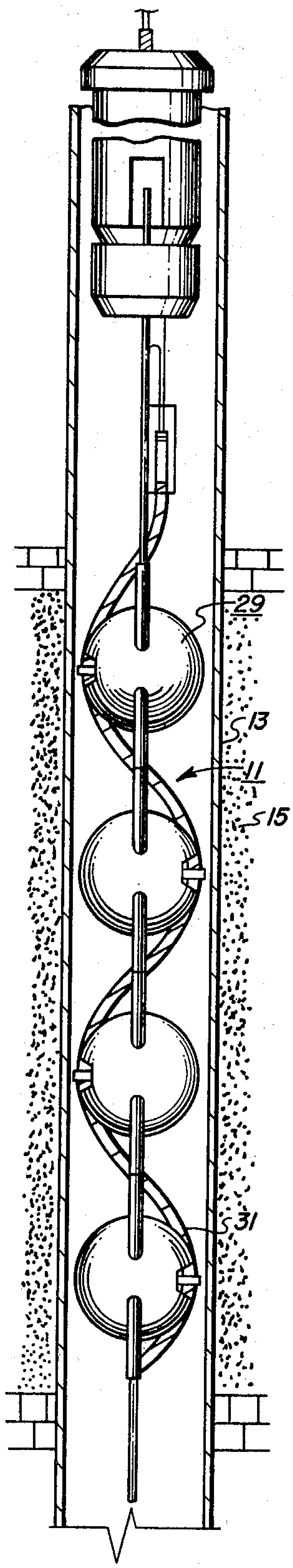

Fig. 2

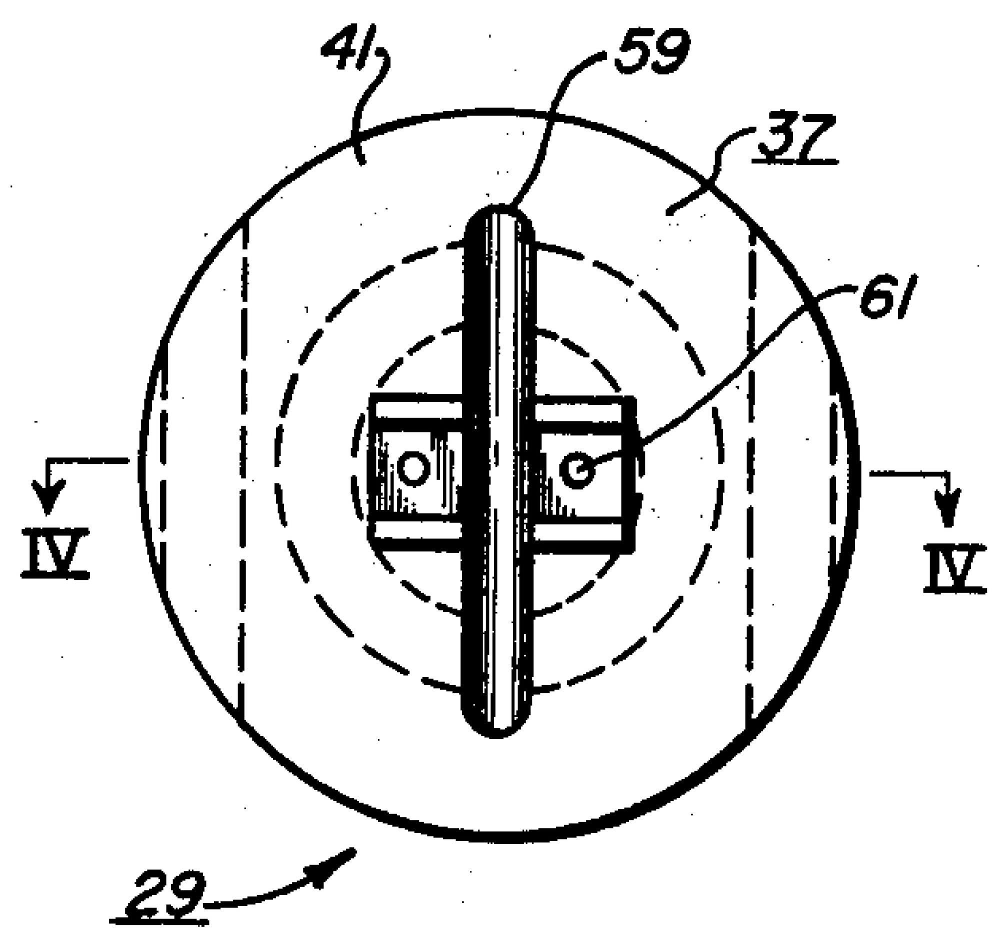

Fig. 3

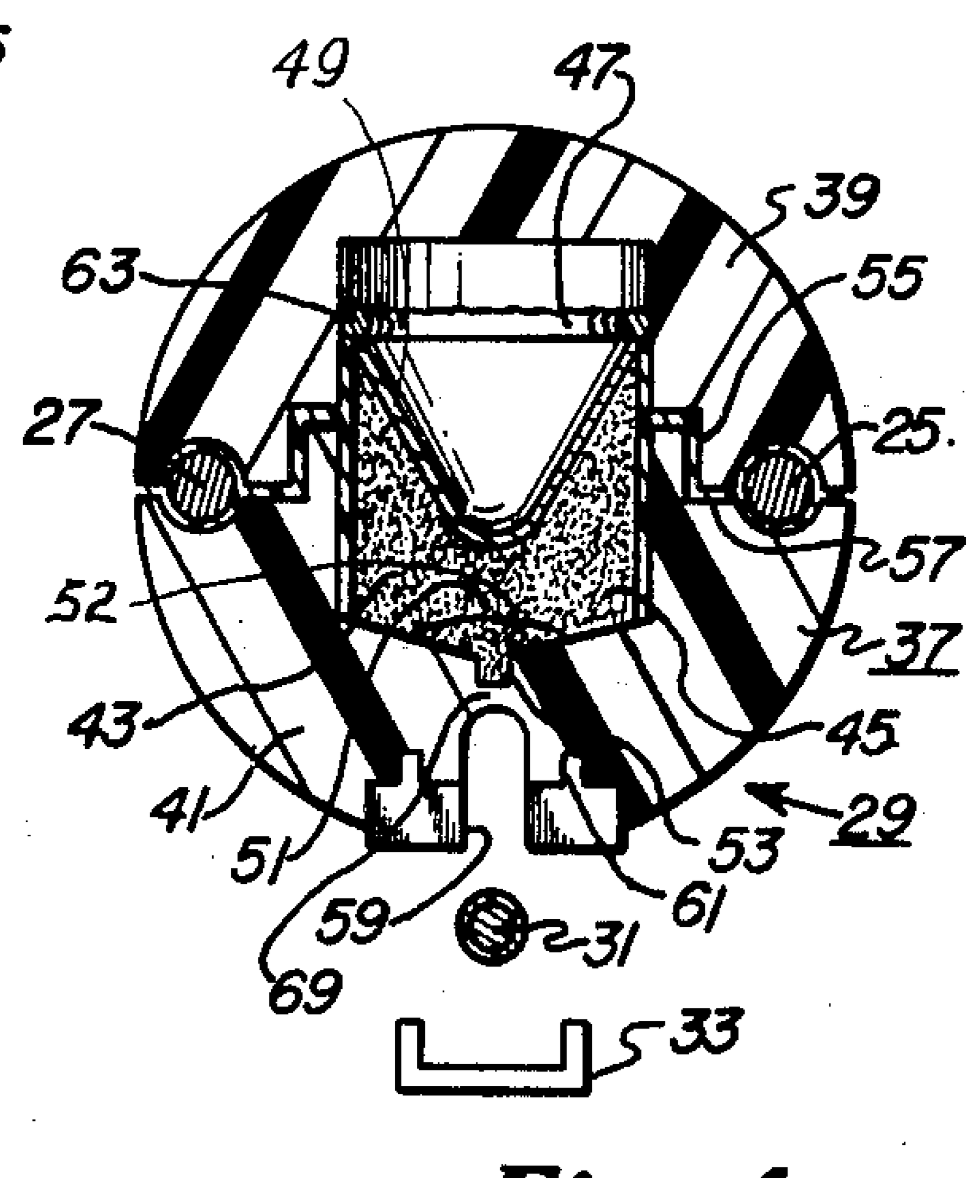

Fig. 4

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ECONOMICAL, TOUGH, DEBRIS-FREE SHAPED CHARGE DEVICE AND PERFORATING GUN ASSEMBLY EMPLOYING SAME

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates in general to well perforating. More particularly, it relates to an improved shaped charge and perforating gun employing the same and adapted to be run through a conduit penetrating subterranean formations in order to perforate therethrough and allow the formation fluids to be produced.

2. Description of the Prior Art

It has been conventional practice in the drilling and completion of oil and gas wells to first drill an earth bore hole of relatively large diameter in which a succession of conduits, generally referred to as casing, are cemented before production. Thereafter, it is desirable to perforate through the casing in order that the fluid in the formation may flow into the well to be produced to the surface. The perforating of the casing usually has been accomplished with the aid of a so-called "gun assembly," which may be a gun perforator using projectiles of the bullet type, or a perforating device using shaped explosive charges. Formerly, it was deemed necessary to perforate through the casing before setting tubing. Frequently, it is desirable to be able to run, or pass, a gun assembly through tubing into the well to effect the desired perforation. It is apparent that the latter imposes restrictions on the size of the gun assembly and any shaped charge employed therein.

In any event, a shaped charge device employed to perforate a conduit should be tough enough to withstand the impacts and pressure it receives as it is run into a well without breaking, should resist invasion of the fluids within the well, should be capable of withstanding the high external pressures and temperatures encountered in the well, should withstand the corrosive fluids often found in the well, should be substantially disintegrated by the detonation of the charge so as to leave only small uniform particles of debris that will not restrict production of fluid, and must be reliably detonatable by an external detonation cord under all well conditions. While the foregoing requirements are severe, the most severe of all is to provide a case that is economical enough to be feasibly employed in relatively poor production wells. In addition, the shaped charge device should be able to be made small enough to be run through tubing, yet effect the desired perforation and penetration.

Metallic cases such as aluminum cases have been employed to satisfy some of the requirements but ordinarily leave more debris in the bore hole than is desirable. On the other hand, the properly designed glass or porcelain charge cases effect the requisite small sized debris particles but have a low mechanical strength and are easily damaged by scraping against the metallic casing or striking a hard object, consequently, are prone to develop leaks. It has also been suggested to employ relatively expensive ceramic material to form cases for the shaped charge device.

Frequently the guns employed in conjunction with the charge cases were sealed against the pressure to reduce the requirements on the charge cases. With sealed guns, it has been suggested to employ plastic cases. It has also been suggested to employ plastic cases in the shaped charge devices in guns which were not sealed against the bore hole fluids for use with shallow, low pressure wells; for example, about 2,000 – 5,000 feet deep. Attempts to employ such plastic cases without a protective gun assembly at greater depths have resulted in failure, however.

Accordingly, none of the prior art devices have been successful in effecting an economical, tough charge case and a simple gun employing the same, that could be employed to depths below 6,000 feet, and satisfy all the requirements delineated hereinbefore.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a front elevational view of a gun assembly employing a shaped charge device in accordance with one embodiment of this invention.

FIG. 2 is a side elevational view of the embodiment of FIG. 1.

FIG. 3 is a rear end view of the shaped charge device illustrated in FIG. 1.

FIG. 4 is a cross sectional view taken along the lines V — IV of FIG. 3 and including a detonation means and holder clamp partially disassembled.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

It is a primary object of this invention to provide an economical shaped charge device having a tough case that satisfies all the requirements delineated hereinbefore and obviates the disadvantages of the prior art devices.

It is also an object of this invention to provide a simple inexpensive gun assembly employing the shaped charge device of the invention.

Referring to FIGS. **1** and **2**, gun assembly **11** is suspended within a conduit **13** penetrating subterranean formations **15**. The gun assembly **11** may be suspended by any appropriate means such as a string of tubing or cable. As illustrated, gun assembly **11** is suspended via its head portions **17** and **19** from a cable head **21** attached to cable **23**. Cable head **21** is so shaped that it may be readily engaged by conventional grappling equipment, if desired. Cable **23** will extend downwardly from appropriate surface equipment including depth measuring means and contain, in addition to a tensile member, appropriate conductors such as a central conductor and the armor, to enable firing the charges at the appropriate depth.

A plurality of lineal rodlike members **25** and **27** are spaced to retain the individual cases and yet form a gun assembly that is adapted to be lowered into the conduit. The rodlike members may comprise ⅛ inch diameter steel wire or equivalent structure and pass through a suitable aperture formed in the shaped charge case, as illustrated in FIG. **2** and discussed in more detail hereinafter. This simple gun assembly is economical, yet has the advantage of delineating misfiring when the bent remnants of the rodlike members are withdrawn from the well after the charges have been fired.

A plurality of shaped charge devices **29** are disposed in spaced apart relationship along the plurality of rodlike members **25** and **27**. The shaped charge devices **29** comprise an outer case containing shaped explosive charges therewithin.

Each of the shaped charge devices **29** are illustrated as being directed horizontally to fire at 180° with respect to the adjacent shaped charge. The charges may be mounted to fire at any angle and at any azimuth. For example, they may be mounted to fire at 120° with respect to each other by employing three rodlike members or spiraling.

The shaped charge devices **29** have a detonation means **31** passing operatively within a groove at the rear thereof for firing the respective shaped charge devices. As illustrated, detonation means **31** is held in the respective groove by a clamp **33**. The detonation means may be that commercially known under the trademark "Primacord," a detonation cord containing, for example, PETN or RDX. PETN is an abbreviation for the compound pentaerythritol-tetranitrite. RDX may be, for example, 98 percent cyclonite and 2 percent wax, cyclonite being an abbreviated term for the chemical compound cyclotrimethylenetrinitramine. Other detonating means of similar properties may be employed.

Detonation means **31** is connected at its upper end to a conventional electric blasting or detonating cap **34** which is fired by an electric current transmitted from an appropriate source; for example, 110 volts from the surface of the earth or from a capacitor bank within head portion **19**, under the control of an operator through conductors in cable **23**. One particular advantage of the gun assembly of this embodiment of the invention is that it may be fired from the top or from the bottom. In employing gun assemblies which do not delineate misfiring, it is advantageous to initiate the firing of the detonating means from the bottom in order that any unfired charges above a misfiring charge will be delineated by the unspent charge, rather than having the lower portion of the gun blown off by firing the charges at the top first.

The failure of the prior art devices to satisfy all of the requirements delineated hereinbefore are overcome by forming the charge cases of the present invention from a frangible plastic material containing about 20 – 40 percent by weight of a macerated filler material.

If more than about 40 percent by weight of macerated filler material is employed in the frangible plastic, a material is obtained that is not satisfactorily dense and tough; it not capable of sealing the charge against fluid invasion at high pressure; and is not capable of withstanding the impacts to which a perforating gun and shaped charge devices are normally subjected in being run into a well to the desired depth within the conduit. On the other hand, if less than about 20 percent by weight of the macerated filler material is employed in the frangible plastic, the resulting product is more like the plastic alone, does not possess adequate compressive strength and does not satisfactorily resist impact and deformation under the high pressure in wells more than about 6,000 feet. In a preferred embodiment, about 30 percent by weight of macerated filler material is employed in the frangible plastic.

Preferred frangible plastics are the thermosetting plastics such as the phenol-formaldehyde copolymer and the phenol-hexamethylenetetramine copolymer. On the other hand, the thermoplastic plastics; such as, acrylonitrile-butadiene-styrene copolymers; may be employed if they have the requisite high temperature resistance to deformation, strength and frangibility.

Preferred macerated filler material comprises cellulose material such as finely particulated wood flour and cellulose fiber like cotton flock. Other materials; such as, finely particulated mica flakes, or even nylon or asbestos; may be employed in forming the macerated filler material.

I have experimented with materials other than plastics and with plastics alone, including exotic thermoplastic plastics and thermosetting plastics and found them not to be satisfactory. Moreover, I have tried tough fibrous materials in the thermosetting plastic and failed to get the requisite good bonding between the fiber and the plastic, resulting in a plastic case that was too brittle and failed to stand up under the necessary impact tests or obtained too soft a product that was more nearly analogous to the plastic alone. In addition, some of the fibrous materials formed large agglomerated debris that was undesirable. I have found, through extensive experimentation that the plastic containing a critical proportion of the macerated filler material, from which the shaped charge case is molded should have the following properties for best results. It should have a flexural strength of at least 10,000 pounds per square inch (p.s.i.) and preferably have a flexural strength greater than 11,000 p.s.i. It should have a minimum impact strength of at least 1.1 foot pounds per inch notch, side (ft. lbs./in.), and preferably have an impact strength of 1.6 ft. lbs./in.; in accordance with the Izod impact test apparatus, American Society for Testing Materials (ASTM) test method D256. It should have a compressive strength of at least 28,000 p.s.i. and preferably greater than 30,000 p.s.i. Cases of such material not only possess the desirable debris and corrosion-resistance characteristics of glass cases, but also contain the strength and trouble free nature of aluminum cases, yet are more economical than any cases heretofore formed. Cases having these properties are obtained with the above delineated plastics containing the critical percentage of the macerated filler material.

A significant feature that I have discovered that allows me to employ the cases of frangible plastic containing the macerated filler material to depths in excess of 10,000 feet is that a greater wall thickness may be employed adjacent the detonation means and still obtain a high enough transmission factor that conventional detonating cord will reliably induce a high order detonation through the wall thickness of the case. I have found that I can obtain detonation through the case wall, yet obtain a case that will withstand deformation to pressures below 10,000 feet in a well if I employ adjacent the detonation means a small area having a wall thickness of from 0.060 – 0.095 inch. This is in contrast to the teachings of prior art patents which indicate that a maximum thickness of 0.050 inch must be employed. If the wall thickness is greater than about 0.095 inch, the detonation force of the detonation means is dissipated within the wall or in destroying the wall. On the other hand, if the wall thickness is less than about 0.060 inch, the case of frangible plastic containing the macerated filler material will not be able to withstand the elevated pressure and the elevated temperature normally encountered in deep wells; for example, wells deeper than about 6,000 – 10,000 feet. Well fluids may then invade the shaped charge devices, resulting in misfiring of the shaped charge devices.

Referring to FIGS. **3** and **4**, shaped charge device **29** has a generally spherical external configuration of case **37**. The spherical configuration is advantageous in withstanding the external pressure. It is particularly advantageous in small shaped charge devices, since it allows a relatively large internal explosive shaped charge per unit volume of external surface. Case **37** is composed of a plurality of sections such as front section **39**, serving as a case cover, and rear section **41**. The front and rear sections are sealable together to resist invasion of well fluids and are generally of sufficient thickness as to be able to resist deformation under the temperature and pressure of well environments and fluids to depths in excess of 10,000 feet.

A generally cylindrically shaped explosive charge **43** is enclosed within case **39**. The shaped charge **43** comprises a pellet **45** of a suitable high-explosive material, such as RDX, having an axially symmetrical conical cavity diverging outwardly toward the front end **47**. A hollowed, complementary shaped, frustoconical liner **49** of a suitable metal is disposed in the conical cavity with the base of the conical liner terminating at the front peripheral edge **47** of the shaped charge **43**. I have found it advantageous to form the high-explosive material in a powder mold by compressing the metal liner inward upon the high-explosive material under high pressures ranging from about 1,000 p.s.i. to about 5,000 p.s.i. This pressure effects the desired higher density of about 1.5 grams per cubic centimeter. Under such pressures the high-explosive material is compressed into a pellet that retains its shape. The shaped explosive charge has in interface **51** formed with respect to a booster charge **52** in the axial recess **53** when the pellet is disposed within the case **37**. Recess **53** defines an inner surface portion at the rear of the rear section **41**. The booster charge **52** of explosive material is loosely disposed in the axial recess **53** adjacent the inner surface portion for boosting the force of the detonation of the detonation means **31**. Any of the conventional high-explosive materials, such as RDX–90, may be employed as the booster explosive material.

The shaped charge may be compressively inserted within the generally similarly and conformingly shaped recess within rear section **41** to assist in preventing deformation of the case **37** and to ensure that the booster charge therebehind will be readily detonated by conventional detonation means **31**. The booster explosive may be tap compacted into the axial recess **53**.

The mating surfaces **55** and **57** of respective front section **39** and rear section **41** are suitably prepared to enable a fluidtight seal to be made whenever the sections are joined. The fluidtight seal is ensured by the use of a suitable fluid resistant bonding material, such as, epoxy resin. The mating surfaces and the bonding material comprise a satisfactory sealing means.

In one method for securing the shaped charge within its case, the case engaging surface and adjacent interior surface portion also may be coated with an appropriate bonding material such as the epoxy resin. As the front mating surface 55 is brought into engagement with rear mating surface 57, the interior portion of the adhesive may flow over the forward edge 47 of the shaped charge to form an annular bead 63. Before the mating surfaces are brought together, the respective rodlike members 25 and 27 are emplaced within respective recesses 65 and 67 which also contain the bonding material, resulting in the case being bonded to the respective rodlike members also.

Thus, upon hardening or firming of the adhesive material, the case is sealingly secured together while forming a means for retaining the shaped charge 43 properly positioned within the case 37.

On the exterior of rear section 41 is provided a groove 59 sized and adapted to snugly receive and retain the detonation means 31 therewithin. Spaced on either side of groove 59 are apertures 61 for receiving a suitable clamp 33 to hold detonation means 31 in groove 59.

As has been previously discussed, a small region 69 intermediate an inner surface portion and an outer surface portion of the rear wall of rear section 41 has a critical thickness within the range of 0.060 – 0.095 inch to ensure that the case will withstand pressures of the well fluids to depths greater than 10,000 feet and yet enable the booster charge to be detonated by conventional detonation means 31.

Other type guns and other shaped charge devices may be employed; for example, a gun comprising a generally flat metal sheet and having inserted thereinto shaped charge devices having a generally cylindrical external shape with a frustoconical end adjacent the detonation means may be satisfactorily employed.

From the foregoing descriptive matter it can be seen that the shaped charge device and a gun employing the same has a case that is tough enough to withstand impacts it receives as it is being run into the well without breaking under the impact and the pressure, will resist invasion of fluids within the well, is capable of withstanding the high external pressures and temperatures encountered in the well, will withstand the corrosive action of fluids often found in the well, will be substantially disintegrated by the detonation of the shaped charge so as to only leave small uniform particles of debris that will not restrict production of fluids from the well, will be reliably detonatable by a conventional external detonation means under all well conditions and is economical enough to be feasibly employed in relatively poor production wells. Moreover, the case and shaped charges may be made small enough to be run through tubing, yet effect adequate perforation and penetration.

Thus, this invention provides a new and improved, compactly arranged shaped charge device having a case that has desirable debris characteristics. It also enables providing a gun perforator using the shaped charges small enough to be run through tubing, yet able to effect penetration of a surrounding well casing and formation. The invention provides the shaped charge devices at an extremely economical cost, since all expenses incidental to the manufacture and use of the shaped charge device are reduced to a minimum. Not only is the cost of the material from which the shaped charge case is fabricated reduced to a minimum, but also the method of manufacture, assembly and subsequent handling and loading all involve a minimum expense.

Although the invention has been described with a certain degree of particularity, it is understood that the present disclosure has been made only by way of example and that numerous changes in the details of construction and the combination and arrangement of parts may be resorted to without departing from the spirit and the scope of the invention.

What is claimed is:

1. In a gun assembly for perforating a conduit in a well penetrating subterranean formations and adapted to fire shaped charge devices in response to a firing means, the improvement comprising:

a. a plurality of lineal, rodlike members in spaced relationship and adapted to be lowered into said conduit,

b. a plurality of shaped charge devices disposed in spaced apart relationship along said plurality of rodlike members; each comprising a case containing a shaped charge, said cases being formed of a frangible plastic containing about 20–40 percent by weight of a macerated filler material, being sealed to resist invasion of well fluids, and being shaped to resist deformation under temperature and pressure of well environment and fluids to depths in excess of 6,000 feet, and

c. flexible lineal detonation means connected with said cases at the rear thereof for firing said shaped charges therewithin and connected with said firing means for initiating detonation of said detonation means.

2. The gun assembly of claim 1 wherein said case has a thickness adjacent said detonation means in the range of 0.060 – 0.095 inch.

3. The gun assembly of claim 1 wherein said case has a generally spherical external configuration to better resist deformation under said temperature and pressure.

4. The gun assembly of claim 1 wherein each case comprises two parts, one part having a shaped charge emplaced therein and each part having a recess for receiving each of said plurality of rodlike members, and said parts are sealingly bonded together about said shaped charge and said rodlike members.

5. The gun assembly of claim 1 wherein said frangible plastic is selected from the group consisting of phenol-hexamethylenetetramine copolymer and phenol-formaldehyde copolymer.

6. The gun assembly of claim 1 wherein said macerated filler material in said frangible plastic is selected from the group consisting of finely particulated cellulose fiber and wood flour.

7. The gun assembly of claim 6 wherein about 30 percent by weight of the macerated cellulose material is employed in a frangible thermosetting plastic.

8. The gun assembly of claim 1 wherein said frangible plastic is phenol-hexamethylenetetramine copolymer and it contains about 30 percent by weight of wood flour.

9. A shaped charge device comprising:

a. a case comprised of a frangible plastic material containing about 24–40 percent by weight of a macerated filler material, being sealable to resist invasion of well fluids and being of sufficient thickness and shape to resist deformation under temperature and pressure of well environment and fluids to depths in excess of 6,000 feet and having an internal cavity adapted to receive an explosive shaped charge, said case having a rear end wall with an outer surface portion thereof adapted for securing detonation means thereon and an inner surface portion adjacent thereto and defining a thickness of said rear end wall between said surface portions in the range of 0.060 – 0.095 inch;

b. booster explosive material loosely disposed in said case contiguous said inner surface portion for boosting the force of said detonation means;

c. explosive shaped charge disposed in said case and extending toward the rearward end of said internal cavity with the rearward end being disposed adjacent said booster explosive material in said case, and having a frustoconical metal liner secured at its forward end, said shaped charge having been compressed sufficiently to obtain the desired density and to retain the shape of said shaped charge; and

d. sealing means sealing said shaped charge and said booster explosive powder within said case.

10. The shaped charge device of claim 9 wherein said case has a generally spherical external configuration to better resist deformation under said temperature and pressure.

11. The shaped charge device of claim 9 wherein said frangible plastic containing said macerated filler material has a flexural strength of at least 10,000 pounds per square inch (p.s.i.), a compressive strength of at least 28,000 p.s.i. and a minimum impact strength of 1.1 foot pounds per inch notch, side, on Izod impact test apparatus in accordance with ASTM test D256.

12. The shaped charge device of claim 9 wherein said frangible plastic is selected from the group consisting of phenol-hexamethylenetetramine copolymer and phenol-formaldehyde copolymer and acrylonitrile-butadiene-styrene copolymer.

13. The shaped charge device of claim 9 wherein said macerated filler material in said frangible plastic is selected from the group consisting of finely particulated cellulose fiber and wood flour.

14. The shaped charge device of claim 13 wherein about 30 percent by weight of the macerated cellulose material is employed in a frangible thermosetting plastic.

15. The shaped charge device of claim 9 wherein said frangible plastic is phenol-hexamethylene-tetramine copolymer and it contains about 30 percent by weight of wood flour.

16. The shaped charge device of claim 9 wherein said frangible plastic is selected from the group consisting of thermosetting plastic and thermoplastic plastic and said macerated filler material is selected from the group consisting of wood flour, cotton flock, fine mica flakes, and finely particulated nylon.

17. The shaped charge device of claim 16 wherein about 30 percent by weight of said macerated filler material is employed in said frangible plastic.

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