April 14, 1964 G. B. CHRISTOPHER 3,128,702

SHAPED CHARGE PERFORATING UNIT AND WELL PERFORATING APPARATUS EMPLOYING THE SAME

Filed May 15, 1959 2 Sheets-Sheet 1

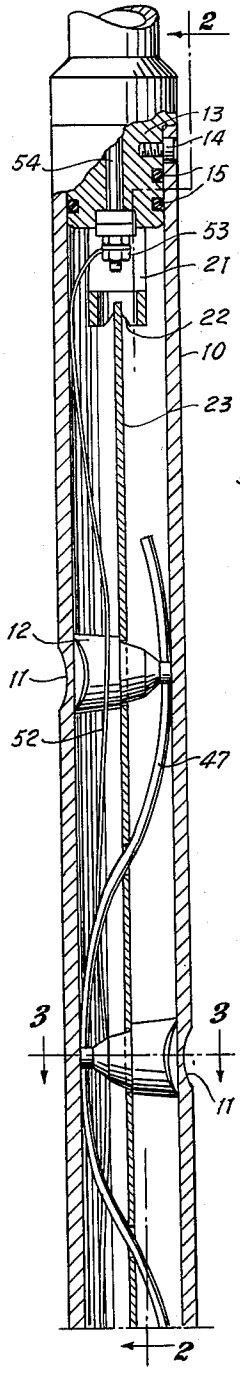


Fig. 1

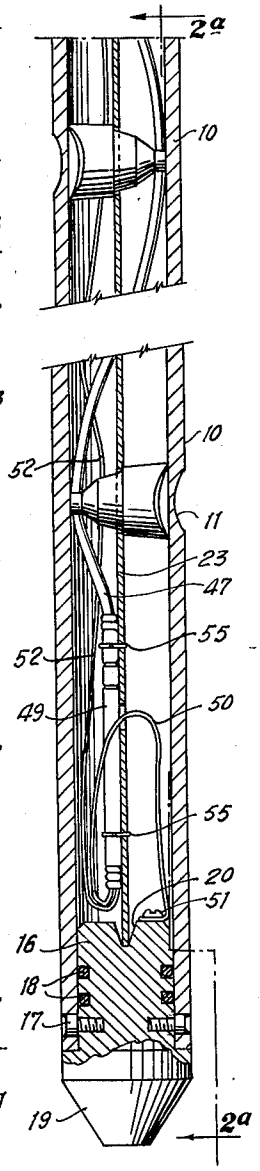


Fig. 1a

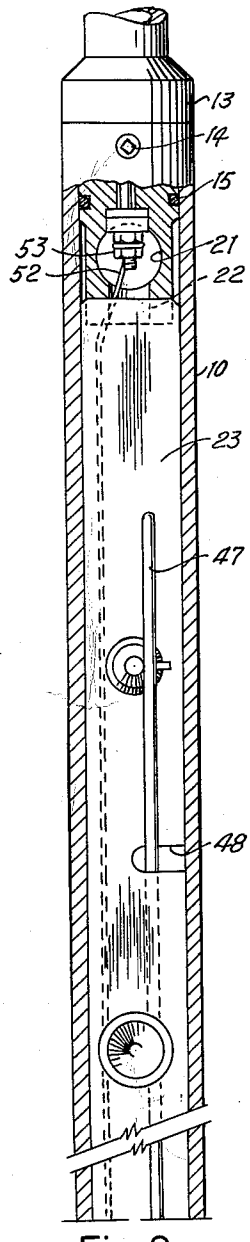


Fig. 2

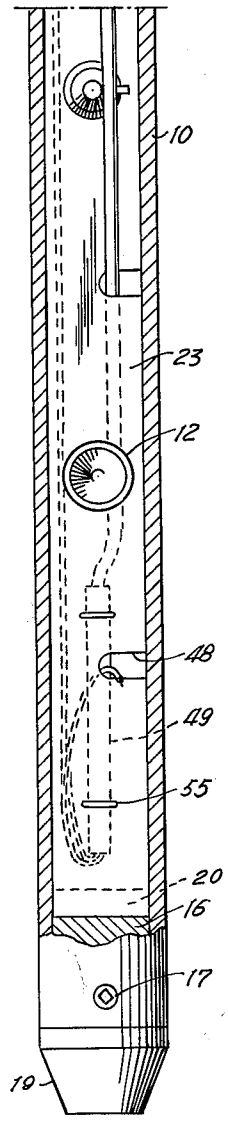


Fig. 2a

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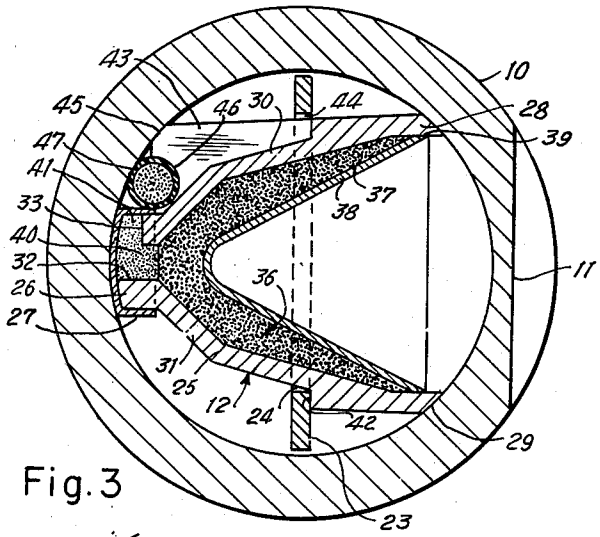


Fig. 3

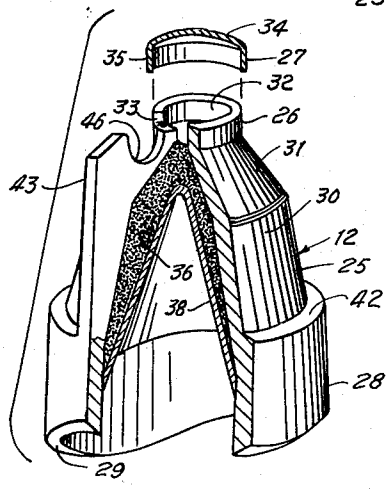


Fig. 5

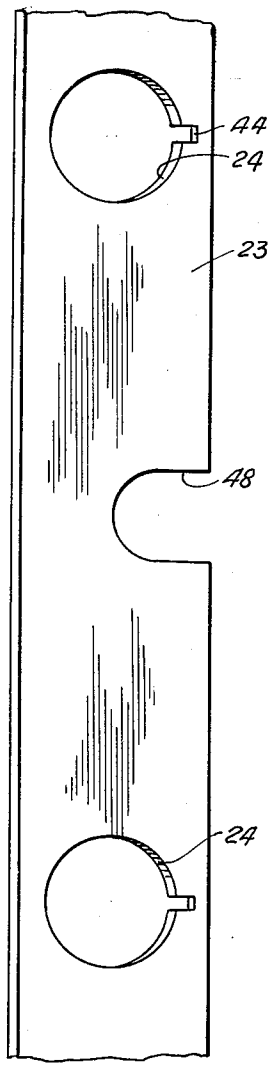


Fig. 4

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SHAPED CHARGE PERFORATING UNIT AND WELL PERFORATING APPARATUS EMPLOYING THE SAME

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3 Claims. (Cl. 102—20)

This invention relates to a shaped charge perforating unit and to well perforating apparatus employing the same.

In the perforation of wells, such as oil, gas or water wells, it is common practice to lower into the well and to fire apparatus including one or more shaped explosive units that are adapted to direct perforating jets outwardly through the wall of the well into the zone to be perforated. Oil, gas, water or other valuable fluid in the formation is given access to the well bore through perforations formed by the jets. The fluid of interest flows into the bore of the well and is raised to the surface of the earth either by pressure existing in the formation or by pumping.

In a recently developed method of completing oil wells known as multiple, tubingless completion, two, three or more strings of small diameter pipe hang side-by-side, cemented in an open hole. There is no single large-diameter oil string as in conventional completions. In effect, each of the small diameter strings is a separate well. In a typical multiple, tubingless completion, the small-diameter strings are made up from 2⅞ in. O.D. pipe such as often is used for production tubing in conventional wells. Each small-diameter string serves as casing. Since no other pipe is used inside these strings, they are also the tubing. Where a single, small-diameter string serves as casing, the well is known as a "slim-hole" well.

In another technique of well completion in accordance with the so-called permanent completion method, after the well is drilled, casing is set in the well down to and including the zone of interest. Small diameter production tubing is lowered into the well from the surface of the earth with the bottom of the tubing near but somewhat above the zone to be perforated. The tubing is suspended from well head equipment which includes the necessary valves for controlling the flow of fluids from the well. The drilling mud is washed from the well and replaced by a clean fluid such as oil or salt water. Thereafter, the perforating apparatus is lowered through the production tubing and out of the bottom thereof to the level of the zone to be perforated. The perforating apparatus is fired to perforate the well. Permanent well completion methods may employ more than one string of production tubing within the casing.

If the apparatus is not destroyed upon firing, it is raised to the surface through the tubing. If the apparatus is expendable, the debris therefrom falls to the bottom of the well.

Since the tubing is of much smaller diameter than the casing, well perforating apparatus which must pass through the bore of the tubing is limited in over-all diameter to a size somewhat smaller than the inside diameter of the tubing. Shaped charge perforating units that are

fixed in horizontal disposition in the carrier of the perforating apparatus are very short and, hence, of limited perforating ability.

Such perforating units are conventionally fired by means of a detonating fuse positioned axially at the rear of the charge units. The fuse occupies space and thus further reduces the space available for the shaped charge perforating units.

It is a principal object of the present invention to provide a shaped charge perforating unit that will most effectively utilize the space available in the bore of a well or in production tubing through which apparatus employing the unit must be lowered.

A further object is to provide a perforating unit having maximum perforating power for a given length.

Another object is to provide an efficient shaped charge perforating unit for use either in hollow carrier well perforating apparatus or in encapsulated units that are protected from the effects of the fluids in the well bore.

Another object is to provide shaped charge well perforating apparatus that leaves substantially no debris in the well after the apparatus has been fired.

Another object is to provide a well perforating apparatus and a shaped charge perforating unit therefor that is particularly adapted for use in either single or multiple, tubingless completion or permanent well completion methods.

Another object is to provide a hollow carrier shaped charge well perforating apparatus including a strip for supporting and properly positioning the perforating units in the hollow carrier.

These, and other objects of the invention as may appear hereinafter, are realized in a well perforating assembly the combination comprising a shaped charge perforating unit having a case, the case being generally rearwardly tapered and symmetrical about a longitudinal axis and including a forward body. A boss is integral with the body and projects rearwardly therefrom. A cap is fitted over the end of the boss. The body provides a main cavity defined by the inner body face. The boss has an axial bore therethrough providing a booster cavity communicating with the rear end of the main cavity, the rear end of the booster cavity being closed by the cap. The boss has a radial channel through its rear end, the inner end of the channel communicating with the booster cavity and the rear opening and outer end of the channel being closed by the cap. A main explosive charge is seated in the main cavity. The charge provides a concavity in its forward end defined by a charge face conforming to a surface of revolution about the axis. A liner is applied to the charge face defining the concavity. A booster charge is seated in the booster cavity and adapted to detonate the main charge. The body has a rearwardly facing circumferential shoulder on the exterior of the body and the case to the rear of the shoulder does not exceed in diameter the diameter of the case at the shoulder. A radial fin integral with the body extends rearwardly from the shoulder, the fin terminating rearwardly in a hook for positioning a detonating fuse at the side of the boss adjacent to the radial channel. A detonating fuse is engaged by the hook and has a portion disposed closely adjacent to the outer end of the radial channel and is adapted to fire

the booster charge. Means for detonating the fuse is provided.

By positioning the detonating fuse at the side of the case, a perforating unit of maximum length can be accommodated in a bore of given diameter. And, in accordance with the invention, symmetrical detonation of the main explosive charge is achieved, notwithstanding the offset position of the detonating fuse with respect to the axis of the unit.

Apparatus for perforating oil wells and the like, in accordance with the invention, may include a vertical tubular carrier having closures in the ends of the carrier and a connector for attaching the carrier to a device for lowering, suspending and raising the carrier in a well. A plurality of shaped explosive charge perforating units are mounted on support structure in the carrier in vertically spaced relation and in positions to direct their jets outwardly through a vertical wall section of the carrier in directions to avoid impingement of the respective jets upon any explosive component of another unit. Each unit includes a case which is generally rearwardly tapered and symmetrical about an axis transverse to the carrier. The case has a forward body, a boss integral with the body and projecting rearwardly therefrom. A cap is fitted over the rear end of the boss. The front face of the body and the rear face of the cap conform to and have a close sliding fit with opposed interior faces of the wall of the carrier. The body provides a main cavity open at the front end. The boss has an axial bore therethrough providing a booster cavity communicating with the rear end of the main cavity. The boss has a radial channel through its rear end, the inner end of the channel communicating with the axial bore. The axial bore and the rear opening and outer end of the channel are closed by the cap. A main explosive charge is seated in the main cavity. The charge provides a concavity in its front end defined by a charge face conforming to a surface of revolution about the axis. A liner is applied to the charge face. A booster charge is seated in the axial bore and is adapted to detonate the main charge. An initiator charge is seated in the radial channel and is adapted to initiate the booster charge. A detonating fuse is trained over the cases of the units at the sides thereof adjacent to the respective initiator charges and is adapted to fire the latter. A detonator for detonating the fuse is provided.

In the drawings:

FIG. 1 is a vertical axial sectional view of the upper portion of apparatus exemplary of the invention for perforating oil wells and the like;

FIG. 1A is a view similar to FIG. 1 of the lower portion of such apparatus, FIGS. 1 and 1A, when taken together, showing the entire apparatus;

FIG. 2 is a sectional view taken on the line 2—2 of FIG. 1 looking in the direction of the arrows;

FIG. 2A is a sectional view taken along the line 2A—2A of FIG. 1A, looking in the direction of the arrows;

FIG. 3 is an enlarged transverse sectional view taken along the line 3—3 of FIG. 1 looking in the direction of the arrows;

FIG. 4 is an enlarged perspective view of the supporting strip for the perforating units of the foregoing apparatus; and

FIG. 5 is an enlarged exploded perspective view, partly in section, of one of the perforating units of the apparatus as shown in FIGS. 1 to 3.

Referring to the drawings, the well perforating apparatus shown has a vertical tubular carrier **10**, preferably made of steel to resist collapse under the pressure of well fluids at the depth at which the apparatus is to be used. The tubular carrier is imperforate; however, vertically spaced recesses provide thin wall sections **11** in front of each of the shaped charge well perforating units **12**. The thin wall sections **11** are strong enough to withstand the pressure of the well fluids, yet thin enough to present a minimum obstruction to the passage of the perforating jets produced when the charge units are fired.

The upper end of the carrier is closed by a plug **13** fitted into the bore of the carrier and retained therein by screws **14**. The plug is sealed in the top of the carrier by O-rings **15** to prevent ingress of well fluids to the interior of the apparatus.

Similarly, the lower end of the carrier is fitted with a closure plug **16** secured to the carrier by screws **17** and sealed therein by O-rings **18**. The bottom end **19** of the lower plug is tapered to facilitate passage of the apparatus downwardly through the production tubing of the well.

The upper face of the lower plug **16** is provided with a diametral groove **20**. Similarly, the upper plug **13** has a depending tubular extension **21** having notches **22** providing, in effect, a groove parallel to the groove **20** in the lower plug. An axial perforating unit supporting strip **23** has its upper and lower ends received in the grooves **22** and **20**, respectively.

The charge unit supporting strip has a width but slightly less than the diameter of the bore of the carrier **10**, the lateral edges of the strip sliding freely on the inner walls of the carrier when the strip is inserted into the carrier. As clearly shown in FIG. 4, the strip **23** has vertically spaced, circular holes **24**. The holes are centered opposite the thin wall sections **11** of the carrier. Each hole receives a shaped charge well perforating unit **12** and positions the latter to direct its perforating jet through the opposed thin wall section of the carrier.

Referring to FIGS. 3 and 5, the charge unit **12** has a generally cup-shaped case including a forward main body **25**, a rearwardly extending boss **26** and a cap **27** fitted over the rear end of the boss.

The front end **28** of the body is annular and is the widest part of the case. The front face **29** of the case is saddle-shaped and conforms to the cylindrical surface of the inner wall of the carrier against which it rests and over which it is free to slide. The main body of the case has an intermediate section **30** in the form of a rearwardly tapering, truncated annulus. The body also has a rear section **31** in the form of a truncated conical annulus tapering rearwardly more abruptly than the intermediate section **30**. The body sections **28**, **30** and **31** form a unitary body member.

The boss **26** is integral with the body and is generally annular in shape. It is the narrowest part of the case. The body and boss portions are in the form of figures of revolution about a common longitudinal axis.

The boss **26** is provided with a coaxial bore **32** extending therethrough. A radial channel **33** extends through the wall of the boss from the rear of the bore **32** to the periphery of the boss. The channel **33** is open at the rear face of the boss.

The cap **27** has a spherical back **34**, the radius of which is almost equal to but slightly less than the radius of the bore of the carrier **10**. The cap has annular sides **35** that fit closely about the periphery of the boss **26**. The sides of the cap may be crimped to the periphery of the boss to retain the cap in place. The cap covers the outer end of the channel **33**, the rear opening of the channel and the rear opening of the bore **32**.

Within the cavity provided by the main body of the case is seated a main shaped explosive charge **36** which is formed of a high explosive material, such as granular waxed RDX, highly densified as by pressing the material into the case. The main charge has a concavity **37** formed in its front face, the concavity being generally conical. However, the concavity **37** may take any of the shapes usual to the hollows of shaped explosive charge units, for example, it may be hemispherical, pear shaped, or the like. Essentially, the concavity is defined by a surface of revolution about the longitudinal axis of the charge unit. To the wall of the concavity is applied the usual liner **38** which may be of copper or similar inert material. The periphery **39** of the base of the liner en-

gages with an interference fit the inner wall of the front end 28 of the charge case.

Seated in the bore 32 at the rear of the main charge, and in detonating relation to the latter, is a charge of booster explosive 40. Continuous with the booster charge and seated in the radial channel 33 is a charge of initiator explosive 41.

The booster charge 40 is a high explosive material having greater sensitivity than the main charge 36 and is adapted to detonate the main charge. The initiator charge 41 is a high explosive material of still greater sensitivity; it is adapted to initiate the booster. The booster 40 and the initiator 41 may consist of unwaxed or pure RDX. The degree of compaction of the booster 40 is slightly less than the degree of compaction of the main charge. As indicated in FIG. 3 by lighter dots, the initiator charge is compacted to a lesser degree than the booster charge and, consequently, has a greater sensitivity.

In loading the charge case, the case is positioned with the booster cavity down and the front opening up. A predetermined quantity of granular pure RDX, sufficient when pressed to fill the initiator and booster cavities, is poured into the case and lightly tamped by hand so that the channel 33, as well as the booster cavity 32, is filled with RDX. The predetermined requisite quantity of waxed granular RDX for the main charge is then poured into the charge case. A liner is placed over the point of the punch and pressed into the top of the explosive charge under very high pressure of the order of 10,000 to 15,000 p.s.i. to form the concavity 37. The punch is withdrawn leaving the liner in position, as shown in FIG. 3. The explosive charge components are thus compressed to the desired degree and occupy the positions indicated.

Because of the rearwardly diminishing cross-section of the interior of the charge case and the offset position of the initiator channel with respect to the booster cavity, and owing to the development of internal friction in the explosive powders as they are compressed, the initiator charge is compacted to a lesser degree than the booster material and the latter to a lesser degree than the main charge There is thus obtained a loaded unit having a sensitive initiator, a booster of less sensitivity, and a main charge of low sensitivity.

The body of the charge case is formed with an external, rearwardly facing, peripheral shoulder 42 which bears against one face of the supporting strip 23 to hold the charge unit with its longitudinal axis horizontal and its front and rear faces aligned with the bore of the carrier. The periphery of the main body immediately to the rear of the shoulder 42 fits snugly within the circular hole 24 to align the axis of the charge with a diameter of the carrier 10. The charge unit is prevented from rotating in the hole 24 by a fin or key 43 that projects radially outwardly from the body 29 and engages a notch or keyway 44 is the supporting strip.

The fin 43 is integral with the main body of the charge and extends rearwardly. It is contoured at the corner 45 to conform to the bore of the carrier 10. A recess 46 is provided in the rear of the fin to form a rearwardly facing hook.

The fin 43 lies in a plane intersecting the longitudinal axis of the charge unit and the axis of the radial channel 33 containing the initiator charge.

The recess receives a portion of a detonating fuse 47 and positions the fuse as close to the initiator charge 41 as the conformation of the charge case and the bore of the carrier will allow. The fuse 47 is similarly trained over the sides of the bosses of each of the perforating units 12, as shown in FIGS. 1 and 2, the fuse being in detonating proximity to the initiator charges of the several units.

The supporting strip 23 has openings 48 positioned intermediate the charge receiving holes 24 through which openings the fuse is passed from charge unit to charge unit. An electric blasting cap 49 is fitted to the bottom of the detonating fuse. One lead wire 50 of the cap is grounded under the head of a screw 51 in the lower plug 16. The other lead wire 52 is led upwardly through the interior of the carrier and connected to an insulated terminal 53. The terminal 53 is electrically connected to an insulated conductor 54 which, in turn, is connected to the insulated conductor in the conventional conductor cable (not shown) by which the apparatus is lowered into the well and by means of which electrical current for firing the blasting cap is delivered to the perforating apparatus.

The blasting cap 49 is secured to the strip 23 by seizings 55.

In an actual perforating apparatus in accordance with the invention, the outside diameter of the hollow carrier is 2 in. and the inside diameter is 1½ in. The charge unit measures 1$\frac{7}{32}$ in. from the rear of the cap 27 to the base of the liner 38. The diameter of the liner at the base is 1 in. and height of the liner is ⅞ in. The total weight of RDX in the initiator, booster and main charges is 5½ grams.

The manner of assembling the components of the perforating apparatus is believed to be apparent from the foregoing description. It may, however, be here noted that the perforating charge units, the detonating fuse, and the supporting strip may be assembled to provide a subassembly which is thereafter inserted as a unit into the tubular carrier. The upper and lower plugs 13 and 16 are aligned with the carrier 10 so that the grooves 22 and 20 are positioned to engage the ends of the supporting strip 23 in a manner to position the several charge units to fire their jets through the thin wall sections 11 of the carrier.

In operation, the perforating apparatus is lowered through the production tubing of a well to a zone to be perforated below the bottom of the tubing. The blasting cap 49 is fired by an electric current delivered from the surface of the earth. The fuse 47 is detonated by the blasting cap and, in turn, fires the perforating units in rapid succession.

Referring to FIG. 3, when the detonation wave in the fuse 47 passes the point of closest tangency to the initiator charge 41 of a perforating unit, the initiator charge is fired by the shock wave from the fuse. A detonation wave travels radially inwardly through the initiator charge and into the booster charge 40. The detonation wave travels forwardly through the booster and axially into the rear of the main charge 36. The detonation progresses symmetrically forwardly through the main charge and attacks the liner 38 to produce a symmetrical perforating jet.

Even though the fuse 47 is positioned at the side of the charge unit, the main explosive charge is detonated axially at the rear. Thus, the detonation of an assymmetrically positioned detonating fuse is utilized to fire the main charge in the desired symmetrical manner. It will be understood that the thickness of the walls of the charge case is such that the main charge is shielded from direct sympathetic detonation by the fuse; the detonation of the main charge is effected through the initiator and booster charges.

The resulting perforating jet is coaxial with the longitudinal axis of the shaped charge unit. It blasts a hole through the thin wall section 11 of the carrier and advances through the well fluids surrounding the carrier and through the well casing and surrounding cement and forms a deep hole in the adjacent earth formation.

Although the carrier is perforated at points where the jets emerge, it is otherwise substantially undamaged. Some slight bulging of the carrier may occur, but such bulging is insufficient to interfere with withdrawal of the apparatus through the tubing after the perforator has been fired. The apparatus is withdrawn to the surface of the earth. The top and bottom plugs may be reused. The carrier and supporting strip are discarded.

Any burrs that may be formed on the outside of the thin wall section **11** by passage of the jet therethrough do not project beyond the outside radius of the carrier and, hence, do not interfere with smooth withdrawal of the apparatus through the tubing.

In accordance with the present invention, maximum utilization of the restricted bore of the carrier is achieved. With the detonating fuse positioned at one side of the charge unit, the charge components, principally the main charge and booster charge, that contribute directly to jet formation may be of a maximum size, taking into account the restricted diameter of the bore of the carrier and standoff requirements of the charge unit.

As seen in FIG. 3, the main explosive charge **35** is formed and positioned in the bore of the carrier so that the lateral blast is evenly distributed around the walls of the carrier. The mass of the explosive along any sector in a transverse plane through the carrier and the axis of the charge unit is approximately inversely proportional to the distance of the explosive from the wall of the carrier.

The apparatus of the present invention leaves little or no debris in the well. Fragments of exploded charge cases and detonating fuse sheath are retained within the carrier and are withdrawn from the well when the apparatus is retrieved.

Although the perforating apparatus shown herein by way of illustration is of the hollow carrier type, it will be understood that the principles of the invention may be applied as well to perforating apparatus that uses encapsulated shaped charge units. An encapsulated unit has an enclosed case that is sealed against intrusion of well fluids. Each unit normally contains but one shaped charge that fires through the end of the case. A number of encapsulated units are formed into a string with the units fixed in horizontal disposition. The units are fired by a length of detonating fuse trained over the outside of the units. Such strings of units are passed into the well through tubing; hence, the length of the units is limited by the inside diameter of the tubing. Side firing of the units in accordance with the present invention is advantageous because it allows the units to be of maximum length and penetrating power.

From the foregoing description it will be understood that various modifications may be made in the exemplary apparatus shown in the drawings. For example, the offset initiator cavity may be in the form of a radial hole drilled through the side of the boss **26**. The cap **27** may be eliminated and the rear of the booster cavity may be closed by a wall integral with the boss. The charge units may be mounted in the hollow carrier by means other than the strip **23**.

I claim:

1. In a well perforating assembly, the combination comprising: a shaped charge perforating unit having a case, said case being generally rearwardly tapered and symmetrical about a longitudinal axis and including a forward body, a boss integral with said body and projecting rearwardly therefrom, and a cap fitted over the end of said boss, said body providing a main cavity defined by the inner body face, said boss having an axial bore therethrough providing a booster cavity communicating with the rear end of said main cavity, the rear end of said booster cavity being closed by said cap, said boss having a radial channel through its rear end, the inner end of said channel communicating with said booster cavity and the rear opening and outer end of said channel being closed by said cap; a main explosive charge seated in said main cavity, said charge providing a concavity in its forward end defined by a charge face conforming to a surface of revolution about said axis; a liner applied to the charge face defining said concavity; a booster charge seated in said booster cavity and adapted to detonate said main charge; said body having a rearwardly facing circumferential shoulder on the exterior of said body, and said case to the rear of said shoulder not exceeding in diameter the diameter of the case at the shoulder; a radial fin integral with said body and extending rearwardly from said shoulder, said fin terminating rearwardly in a hook for positioning a detonating fuse at the side of said boss adjacent to said radial channel; a detonating fuse engaged by said hook and having a portion disposed closely adjacent to the outer end of said radial channel and adapted to fire said booster charge; and means for detonating said fuse.

2. Apparatus for perforating oil wells and the like comprising: a vertical tubular carrier; closures in the ends of said carrier; a connector for attaching said carrier to a device for lowering, suspending and raising said carrier in a well; a plurality of shaped explosive charge perforating units; support structure mounting said units in said carrier in vertically spaced relation and in positions to direct their jets outwardly through a vertical wall section of said carrier in directions to avoid impingement of the respective jets upon any explosive component of another said unit; each said unit including a case, said case being generally rearwardly tapered and symmetrical about an axis transverse to said carrier, said case having a forward body, a boss integral with said body and projecting rearwardly therefrom, and a cap fitted over the rear end of the boss, the front face of said body and the rear face of said cap conforming to and having a close sliding fit with opposed interior faces of the wall of said carrier, said body providing a main cavity open at the front end, said boss having an axial bore therethrough providing a booster cavity communicating with the rear end of said main cavity, said boss having a radial channel through its rear end, the inner end of said channel communicating with said axial bore, said axial bore and the rear opening and outer end of said channel being closed by said cap, a main explosive charge seated in said main cavity, said charge providing a concavity in its front end defined by a charge face conforming to a surface of revolution about said axis, a liner applied to said charge face, a booster charge seated in said axial bore and adapted to detonate said main charge, and an initiator charge seated in said radial channel and adapted to initiate said booster charge; a detonating fuse trained over the cases of said units at the sides thereof adjacent to the respective initiator charges and adapted to fire the latter; and a detonator for detonating said fuse.

3. Apparatus for perforating oil wells and the like comprising: a vertical tubular carrier; closures in the ends of said carrier; a connector for attaching said carrier to a device for lowering, suspending and raising said carrier in a well; a plurality of shaped explosive charge perforating units; support structure mounting said units in said carrier in vertically spaced relation and in positions to direct their jets outwardly through a vertical wall section of said carrier in directions to avoid impingement of the respective jets upon any explosive component of another said unit; each said unit including a case, said case being generally rearwardly tapered and symmetrical about an axis transverse to said carrier, said case having a forward body, a boss integral with said body and projecting rearwardly therefrom, and a cap fitted over the rear end of the boss, the front face of said body and the rear face of said cap conforming to and having a close sliding fit with opposed interior faces of the wall of said carrier, said body providing a main cavity open at the front end, said boss having an axial bore therethrough providing a booster cavity communicating with the rear end of said main cavity, said boss having a radial channel through its rear end, the inner end of said channel communicating with said axial bore, said axial bore and the rear opening and outer end of said channel being closed by said cap, a main explosive charge seated in said main cavity, said charge providing a concavity in its front end defined by a charge face conforming to a surface of revolution about said axis, a liner applied to said charge face, a booster charge seated in said axial bore

and adapted to detonate said main charge, and an initiator charge seated in said radial channel and adapted to initiate sai booster charge; a detonating fuse trained over the cases of said units at the sides thereof adjacent to the respective initiator charges and adapted to fire the latter; a hook integral with said case holding said fuse adjacent to the respective initiator charges; and a detonator for detonating said fuse.

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