JET PERFORATING APPARATUS
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This application is a continuation of copending application Serial No. 26,459, filed May 3, 1960, now abandoned.

The present invention relates to apparatus for perforating well casings in bore holes and creating cavities in the formations adjacent thereto in oil field recovery and well completion operations, and more particularly to an improved apparatus for accomplishing such perforating and for creating such cavities by means of so-called jet perforators, by which is meant perforating devices that employ fixed shaped explosive charges designed to produce the "jet effect" or "Munson effect".

In order to obtain the maximum oil recovery and rate of flow, it is desirable that the diameters of the holes created by the jet streams in the well casing and the surrounding geological formation be relatively large and the depth of penetration as great as possible, and that the holes be free of obstructions.

Accordingly, it is a principal object of the present invention to provide improved jet perforating apparatus for creating larger diameter, obstruction-free holes in the well casing, surrounding cement if any, and the surrounding geological formations, while at the same time, obtaining maximum penetration into the formation.

It is a further object to provide jet perforating apparatus which substantially precludes the possibility of plugging of the hole by the "carrot" resulting from the collapsed charge liner by forming holes in the well casing and producing formation having diameters larger than the maximum diameter of the "carrot."

A still further object is to provide an improved apparatus for perforating well casing by creating jet streams of greater mass than can be obtained by using conventional methods.

Briefly stated, the illustrated embodiment of the invention provides an improved jet perforating unit having a novel shaped charge, shaped charge jacket, and liner configuration among its features. The shaped charge is enclosed by a complementary, generally stepped funnel shaped charge jacket having a wall structure formed by concentric cylindrical and conical surfaces of revolution. A ductile metallic insert or backing member of high density and conforming to the general shape of the charge exterior is disposed between the explosive charge and the jacket. The cavity formed in the shaped explosive charge is defined by a conical surface of revolution with its apex nearest the point of detonation and a frusto-conical surface of revolution, the base of the conical surface being with the smaller end of the frusto-conical section. The larger end or base of the frusto-conical section is located near the open end of the jacket. A metallic liner is inserted into the cavity described above, the outside surface of the liner complementing the shape and the size of the cavity in the explosive and being contiguous with the explosive. The included angle of the conical surface of revolution is greater than the included or cone angle of the frusto-conical surface of revolution. Thus upon collapse of the liner, the initial jet stream associated with the conical surface of revolution will have a lesser velocity than the jet stream associated with the frusto-conical surface of revolution. Therefore, the jet stream associated with the frusto-conical section will overtake and augment the jet stream associated with the conical section, causing the mass per unit length of the jet stream to be increased.

The invention, both as to its organization and method of operation, together with further objects and advantages, will best be understood by reference to the following description taken in connection with the accompanying drawing, in which:

FIG. 1 illustrates a typical installation of a perforating gun in a well casing, shown in longitudinal section, and illustrating the operation of the jet perforating apparatus of the present invention;

FIG. 2 is a view partially in section taken along the lines 2-2 in FIG. 1, illustrating details of one of the jet perforating units embodied in the gun shown in FIG. 1;

FIG. 3 is a cross-sectional view of the jet perforating unit shown in FIG. 2; and

FIG. 4 is an exploded view of the principal portions of the jet perforating unit of FIGS. 2 and 3, with FIGS. 4a, 4b, 4c, 4d, and 4e illustrating the individual portions.

Referring now to the drawing and particularly to FIG. 1, an improved jet perforating apparatus is there illustrated in a jet type perforating gun indicated generally at 10. The tubular gun barrel or housing 11 of the gun 10 has a plurality of explosion ports 12 spaced apart along the length thereof. The ports 12 are adapted to receive fluid seals to exclude fluid from the gun housing 11 prior to detonation of the charges. These ports may also be spaced circumferentially of the gun housing in any desired manner so that the charges can be directed radially through targets in the well casing 14 and into the adjacent geological formation 15. The upper end of the housing or gun barrel 11 is connected to the lower end of the cable socket 15. The cable socket 15 is anchored to the lower end of a cable 16 which is employed to lower and raise the gun into and out of the casing well which is to be perforated. At its lower end the barrel or housing 11 is closed by a suitable closure cap or bull plug 17. The raising and lowering of the cable 16 which includes one or more electrical conductors (not shown) is controlled from the earth's surface by conventional means represented by the control panel 20. A suitable power source 21 above the surface of the ground may be employed to energize the control panel 20 and for electrically firing the charges within the gun 10. The electrical circuitry utilized for controlling the cable and for firing the charges is conventional and therefore no details are shown.

Referring now more particularly to FIGS. 2, 3, and 4 of the drawing, within the housing 11 there are disposed a plurality of jet forming explosive perforating units 22. Each of the jet forming explosive perforating units 22 includes a shaped charge 23 of high explosive which may be of any suitable type having the desired properties of high velocity, relative insensitivity to shock and relatively high decomposition temperature. In a preferred form the explosive used for the shaped charge 23 may be of the type known in the art as "Cyclonic." The shaped charge 23 has a novel configuration as shown and described herein, and, is enclosed within a jacket 24, preferably of aluminum, which jacket has a novel generally stepped funnel shaped wall configuration complementing that of the shaped charge.

The jacket 24, which may have a wall thickness of about 0.025 inch in the illustrated embodiment employed with a 4 inch O.D. gun, provides a tough outer shell for the charge which is adapted to prevent damage to the charge prior to detonation. The jacket 24 is formed to provide an open firing end 25 and a reduced diameter disk shaped detonating end 28 which is closed except for a small central opening 19. The wall structure of jacket 24 includes three cylindrical surfaces of revolution which are pro-
gressively larger in diameter in a direction extending from the detonating end to the firing end of the jacket. At the detonating end of the jacket 24 is a cylindrical portion 26 which is connected to the disk-shaped end portion 28. Portion 26 is connected to the central cylindrical surface of revolution 30 by means of a frusto-conical surface of revolution 31. The sides of the surface of revolution 31 define an included angle 29 of approximately 90° in the illustrated embodiment. A frusto-conical surface of revolution 32 extends between the cylindrical surface of revolution 30 and the cylindrical surface of revolution 33 at the open end of the jacket. The sides of the frusto-conical surface of revolution 32 define an included angle 38 of approximately 60° in the illustrated embodiment.

The jet perforating unit 22 includes means for providing momentarily in predetermined varying degrees, resistance to the expansion of the gaseous products and the explosion shock waves released on detonation of the shaped charge. The means for accomplishing this consists of a ductile high density metal insert or backing member 27 which has a concentric generally stepped funnel shape having its widest portion facing the target, which conforms to and is fitted against the inside wall of the jacket at portions of the charge jacket away from the firing end as shown in FIG. 2. The insert 27 is preferably made of an inert material and in the illustrated embodiment is of copper having a comparatively uniform wall thickness of approximately 0.020 inch. Due to the geometry of the liner 37 with respect to the cavity 34 the included or cone angle 39 at the apex of the liner 37 is approximately 75 degrees and the sides of the frustum-like skirt portion 40 of the liner 37 form an included or cone angle 48 of approximately 45 degrees.

The jet stream associated with the cone angle 39 at the apex of the liner will be initiated before the jet stream associated with the cone angle 48 inasmuch as it is closer to the explosion initiation point at the detonating end of the jacket. However, as the cone angle 48 is smaller than the cone angle 39, the jet stream associated with the cone angle 48 will have a higher velocity than the jet stream associated with the cone angle 39. As a result, the latter initiated jet stream associated with angle 48 will overtake and augment and reinforce the jet stream associated with angle 39, resulting in a composite jet stream of relatively great mass per unit length.

Referring now to FIG. 2 of the drawing, the various perforating units 22 are mounted in the gun 10 by threading the respective units on the detonating cord 42. Each of the jet perforating units 22 includes means for positioning the charges consisting of rubber envelopes 41 shown in FIGS. 2, 3, and 4b. The envelopes 41 surround the respective charge jackets 24 except for the end opposite the detonating end. The envelopes 41 are provided with necked portions 46 with openings 43 for the detonating cord to pass through the respective units. In order to prevent binding of the detonating cord within the openings 43 it has been found advantageous to utilize a harder grade of rubber in the zone of the detonating opening 43. This hardened portion 44 is indicated in FIG. 3 of the drawing. In the gun 10 opposite the respective ports 12 there are charge mounting recesses 45 into which the neck portions 46 of the envelope are fitted. The ports 12 are each threaded as indicated at 49 and counterbored at 47 for the reception of the fluid seal plug 59 of a suitable material such as plastic or aluminium which cooperates with a disk shaped aluminium member 51 having a central passage 53 (FIG. 4e) for positioning the conical axis of the charge cavity in central alignment with its port 12. A positioning sleeve 52 is placed between the disk shaped member 51 and the plug 59, the threaded portion of which may be partially hollow dependency.

Referring now to the mode of operation of the jet perforating gun embodying the present invention, the gun 10 is lowered into the well casing 14 to the desired location for the perforating operation by means of the cable 16 and control panel 20. The jet stream 42 is then detonated by employing electrical control means in control panel 20 and an electrical conductor in cable 16 to electrically ignite a blasting cap (not shown) to detonate cord 42 which, in turn, detonates the various charges 23.

The detonation of the charges as described above produces jet streams having greater mass per unit length than jets produced by conventional means and causes holes to be created in the well casing and the producing formation of larger diameter and greater depth than has been possible heretofore. Specifically, this jet perforating apparatus of the present invention has been tested in comparison with conventional charges on standard Berea targets each consisting of a 16 inch length of approximately 5 inch diameter pipe with a ¾ inch thick steel plate welded over one end and a 15 inch core of Berea sandstone soaked inside of the pipe with water. The test results demonstrated that when a conventional charge was used, a ¾ inch diameter hole was obtained in the steel plate and the hole in the sandstone was completely blocked by the "carrot" at a depth of 6% inches from the face of the steel plate. However, when the improved jet perforating unit employing the present invention was used the
steel plate hole diameter was much larger, namely 5\% inch in diameter as opposed to only 3\% inch in diameter for the conventional charge. In addition, the hole depth was between 9 and 10 inches with no "carrot" plugging the hole in the sandstone.

It will be obvious to those skilled in the art that the described apparatus provides an improved arrangement for employing jet perforating techniques and is a distinct advance in the art.

While there has been described what is at present considered to be the preferred embodiment of the invention, it will be understood that various modifications may be made and will be suggested to those skilled in the art. All such modifications are intended to be included within the scope of the invention as best defined in the appended claims wherein there is claimed.

What is claimed is:

1. A jet forming explosive perforating unit having a detonating end and a jet discharge end and comprising a heavy ductile metal backing member provided with a plurality of cylindrical sections spaced axially from each other and having decreasing diameters in a direction extending from the jet discharge end of said perforating unit to the detonating end of said perforating unit, said backing member also being provided with frusto-conical sections interconnecting the adjacent ends of the cylindrical sections of said member and having a stepped and progressively greater wall thickness from end to end in a direction extending from the jet discharge end of said perforating unit to the detonating end of said perforating unit, the wall thickness adjacent the detonating end of said perforating unit being approximately 0.090 inch, a shaped explosive charge disposed within said backing member and provided with a bi-angular and generally conical cavity at the jet discharge end of said perforating unit, the walls of said cavity comprising a frusto-conical section having a predetermined cone angle and a conical section having a cone angle which is greater than said predetermined cone angle, and a liner having a shape complementary to the shape of said cavity positioned in said cavity.

2. A jet forming explosive perforating unit having a detonating end and a jet discharge end and comprising a heavy ductile metal backing member provided with a plurality of cylindrical sections spaced axially from each other and having decreasing diameters in a direction extending from the jet discharge end of said perforating unit to the detonating end of said perforating unit, said backing member also being provided with frusto-conical sections interconnecting the adjacent ends of the cylindrical sections of said member and having a stepped and progressively greater wall thickness from end to end in a direction extending from the jet discharge end of said perforating unit to the detonating end of said perforating unit, the wall thickness adjacent the detonating end of said perforating unit being approximately 0.090 inch, a shaped explosive charge disposed within said backing member and provided with a bi-angular and generally conical cavity at the jet discharge end of said perforating unit, the walls of said cavity comprising a frusto-conical section having a predetermined cone angle of approximately 45 degrees and a conical section having a cone angle of approximately 75 degrees, and a liner having a shape complementary to the shape of said cavity positioned in said cavity.

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