The present invention relates to well perforating apparatus, and more particularly to improved apparatus for perforating wells by means of both shaped charges and projectiles in a unitary apparatus in one operational step. For a number of years, wells drilled for the production of oil have been perforated using bullet or projectile type perforating devices. In recent years this practice has been supplanted to some extent by utilization of explosive perforating devices of the so-called "hollow" or "shaped" charge type. Various representative types of perforating devices have certain advantages.

It is common to both types of perforating operations to mount the perforating units in an elongated carrier capable of being lowered to the desired position in the well borehole by means of a wire line or sometimes on the end of a tubing string. Conventional shaped charge perforating units are frequently fabricated in the form of thick walled, precision machined, alloy steel cylinders. The carriers are relatively expensive and it is desirable to reuse them as many times as possible. In practice, a large number of shaped charges are essentially simultaneously detonated in the carrier. A relatively small part of the explosive energy from a detonating shaped charge is concentrated in the jet, while a relatively large part is directed against the inside wall of the carrier, particularly at points to the side and rear of the shaped charge. It has been observed that deformation most often occurs in these regions in a carrier after a number offirings.

Accordingly, it is an object of the present invention to provide improved apparatus for the perforating of wells whereby a portion of the explosive energy developed in a hollow, pressure resistant, sealed carrier by detonation of shaped charges is utilized to propel a projectile from a barrel through adjacent well casing and cement and into surrounding earth formations.

It is another object of the present invention to provide improved apparatus for the perforating of wells whereby an individual shaped charge or a projectile barrel may be positioned in any of a plurality of different directions in any one transverse plane of a hollow, pressure resistant, sealed carrier.

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The foregoing and other objects of the invention as may appear hereinafter are realized in a well perforating apparatus including a hollow, elongated, pressure resistant, sealed carrier, adapted to be lowered into a well borehole with means for lowering the carrier into the well borehole. A shaped charge perforating unit is mounted within the hollow of the carrier and positioned to fire its jet outwardly through a wall of the carrier. A projectile barrel is mounted on the wall of the carrier and adapted to be lowered into a well borehole outwardly of the carrier. The breech of the barrel is located within the hollow of the carrier, preferably closely adjacent to the side of the perforating unit. A projectile is seated in the bore of the barrel at the breech end. The barrel provides a gas passage in the breech end through which gas under high pressure in the hollow of the carrier acts upon the base of the projectile to propel the latter from the barrel. Means is provided for detonating the shaped charge perforating unit to form a jet that travels outwardly through a wall of the carrier, and to provide high gas pressure in the hollow of the carrier to propel the projectile from the barrel.

In the drawings:

FIGURE 1 is an axial sectional view of a portion of a well within which is disposed a hollow carrier perforating apparatus constructed in accordance with the present invention; and

FIGURE 2 is a transverse sectional view taken along line 2--2 of FIGURE 1 showing the hollow carrier with a shaped charge perforating unit and two projectile perforating units mounted therein in accordance with the invention.

Referring to FIGURE 1, the well perforating apparatus 10 has a hollow, pressure resistant, sealed carrier 11, a bullet plug 12, a casing collar locator 15, and a cable head 16, to which is secured a cable 18 for raising the apparatus in the well. The hollow carrier 11 is provided with a plurality of port seal plugs 16 and projectile barrels 17 mounted flush with the outside surface of the carrier.

Referring now to FIGURE 2, the carrier 11 is provided with laterally directed threaded openings or ports 29a, 29b, 29c, which receive respectively the perforating unit mounting sleeve 25 and the projectile barrels 17a and 17b.

The shaped charge perforating unit 18 has a case or shell 19 made of any suitable material, such as frangible metal or plastic, with the front section 20 of the case being substantially cylindrical and open at the front end, a tapered conical mid-section 21, and a cylindrical rear section 22 with a smaller cylindrical boss 23 on its end received in the truncated conical recess 24b in the inner wall of the carrier 11.

The forward end of the case is supported by an assembly including the sleeve 25 and an annular washer 26. The sleeve has a shoulder 27 engaging the front of the washer, the latter being seated in a recess 28 in the front of the case. The forward end of the sleeve seats in the port 29a.

A port plug 16 with a thin end wall 30 is threaded into port 29a compressing a sealing ring 31a, which may be made of a soft metal, plastic or rubber, providing a liquid tight seal between the port plug 16 and the carrier 11. The port plug 16 forces the sleeve 25 against the annular washer 26 which, in turn, forces the boss 23 firmly into recess 24b, maintaining the shaped charge in axial alignment with the port opening 29a.

The liner 32 of the shaped charge is a substantially conical member, composed of any suitable material, preferably a metal of high density such as copper, steel or brass. The main explosive charge 33 is contained between the liner 32 and the cylindrical and tapered sections of the shaped charge case 19. The charge 33 is a body of highly compressed detonating explosive such as trinitrotoluene (TNT), pentaerythritol tetranitrate (PETN), or cyclotrimethylene trinitramine (RDX) or Cyclonite, preferably desensitized. A booster charge 34 is contained in a conical bore at the rear of the mid-section of the charge case 19, and is a body of more sensitive detonating explosive, such as pure Cyclonite, capable of being initiated by a detonating fuse 35, such as Primacord. The cylindrical rear section 22 of the shaped charge case contains an opening or passage 36 perpendicular to the
axis of the shaped charge case 19 and adjacent to the booster charge 34, through which is threaded a length of detonator fuse 35. The fuse extends similarly through the plurality of shaped charge units mounted axially along the carrier.

The projectile gun barrels 17a and 17b are located in the same transverse plane as the shaped charge unit with their axes positioned at angles of approximately 120° to the axis of the shaped charge. The projectile gun barrel 17a is threadably mounted in port 29b, which is preferably of the same dimensions and threading as that of port 29a. A sealing ring 31b is used to prevent entry of liquid into the hollow carrier. A rear opening 37 is provided in the breech end of the gun barrel to allow high pressure gas generated by the detonation of the shaped charge to propel the projectile 38 from the barrel through the well casing into the earth formation. The breech end of gun barrel 17a is provided with an intumescence flange 39 on which the projectile is seated. The projectile 38 has a cylindrical body, a flat base, and a conical nose. The projectile is seated in the gun barrel with a sealing plug 40. The sealing plug may be a soft metal deburring type seal or it may be made of rubber, neoprene or plastic material.

Gun barrel 17b in FIGURE 2 is constructed and mounted in a like manner as gun barrel 17a. In gun barrel 17b is illustrated an alternate form of projectile in the shape of a metal disc 41 sealed by a flexible disc 42, which may be made of rubber, neoprene, or plastic material.

In FIGURE 2, the conical recesses 24a, 24b, 24c in the inside carrier wall are positioned opposite the respective ports 29c, 29a, 29b. When the ports in the carrier wall are all of the same dimension and threading, such an arrangement permits the mounting of either a shaped charge or a projectile barrel in any port in the carrier.

In operation, the perforating apparatus 10 is lowered from the surface down the wellbore by use of cable 15. The signals from the casing collar locator 13 are transmitted to the surface through cable 15 and recorded or displayed by conventional equipment (not shown). These signals permit the operator to position the perforating apparatus at the depth of the earth formation selected for perforation. The shaped charges in the pressure resistant, sealed carrier 11 are detonated essentially simultaneously by means of an electric blasting cap (not shown) attached as is conventional to the length of detonating fuse 35. Current for firing the blasting cap is supplied from the surface through cable 15. The jet formed from the shaped charge liner 32 by the detonation of explosive charge 33 penetrates the port plug end wall 30, the well casing, cement and earth formation. The detonation also shatters the frangible shaped charge case 19, releasing detonation energy having horizontal components acting principally along two lines approximately 120° to either side of the axis of the shaped charge. These energy components occurring simultaneously with the pressure build-up inside the pressure resistant carrier 11 from the gases produced by the explosive charge 33 cause the projectiles 38 and 41 to be propelled at high velocity from the gun barrels 17a, 17b with sufficient energy to penetrate the well casing, cement and earth formation.

After the shaped charges and projectiles are fired, the perforating apparatus is returned to the surface where the perforated seal ports and debris are removed from the hollow carrier. The same perforating apparatus may be reloaded with shaped charges and projectiles for reuse.

A more complete utilization of the explosive energy developed by detonating the shaped charges is realized in the present invention than has heretofore been obtained with other shaped charge perforating apparatus. It is understood that the apparatus herein described and illustrated is subject to wide modification in form and detail without departing from the spirit of the invention. For example, the shaped charge unit described and depicted may be replaced with any shaped charge commonly used in the art. Accordingly, the specific embodiments herein are to be considered merely illustrative and not as restricting the scope of the following claim.

I claim:

A well perforating apparatus comprising in combination:

(a) an elongated, tubular, pressure resistant, hollow, sealed carrier adapted to be lowered into a well borehole;

(b) means for lowering said carrier into a well borehole;

(c) a shaped charge of detonating explosive material in the form of a body of revolution about an axis, said charge providing a generally conical cavity at one end, and having a rearwardly tapering side portion adjacent the other end;

(d) a liner applied to the surface of said charge defining said cavity;

(e) means for detonating said shaped charge at said other end;

(f) means mounting said charge within said carrier with its axis extending transversely of said carrier;

(g) a gun barrel extending through the wall of said carrier and having its muzzle end sealingly mounted in said wall and its breech end extending into the hollow of said carrier, the axis of said barrel intersecting an element of the tapering side portion of said charge at substantially a right angle and intersecting the axis of said charge at an acute angle, the breech end of said barrel being positioned closely adjacent to the tapering side portion of said charge, and said barrel providing an opening in its breech end facing said tapering side portion; and

(h) a projectile seated in the bore of said barrel with the base of the projectile directly facing the tapering side portion of said charge through said opening.

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