United States Patent

Vann

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[54] **TUBING CONVEYED PERMANENT COMPLETION METHOD AND DEVICE**

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[52] **U.S. Cl.** **166/297,** 166/313, 166/55, 175/4.56

[51] **Int. Cl.**.....**E21b 43/116,** E21b 43/12

[58] **Field of Search**.....166/297, 313, 314, 55, 254; 175/4.56, 4.6

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[57] **ABSTRACT**

Method and apparatus for effecting a dual completed well wherein the lower zone is packed off or isolated from the upper zone prior to perforating either zone; the upper zone is then completed, whereafter the lower zone is perforated. In perforating the lower zone a casing perforating gun, gun firing mechanism, and packer are run into the hole with the gun being suspended below the packer and properly positioned with respect to the borehole. The lower zone is then isolated and the tubing to the packer is removed. The upper zone is then completed, tested, and shut-in, if desired. The tubing is again flow connected to the packer, swabbed clean, and then the casing perforator is actuated, with the production from the lower zone being free to flow to the surface of the earth at the moment the lower perforations are made by the gun. The packer, gun and the firing mechanism are left in the hole.

26 Claims, 15 Drawing Figures

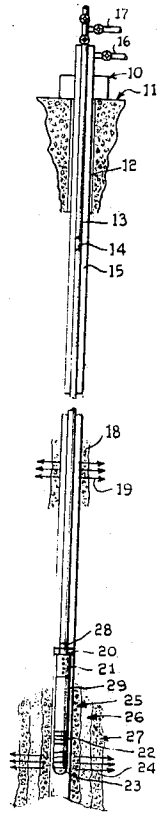

Fig. 1

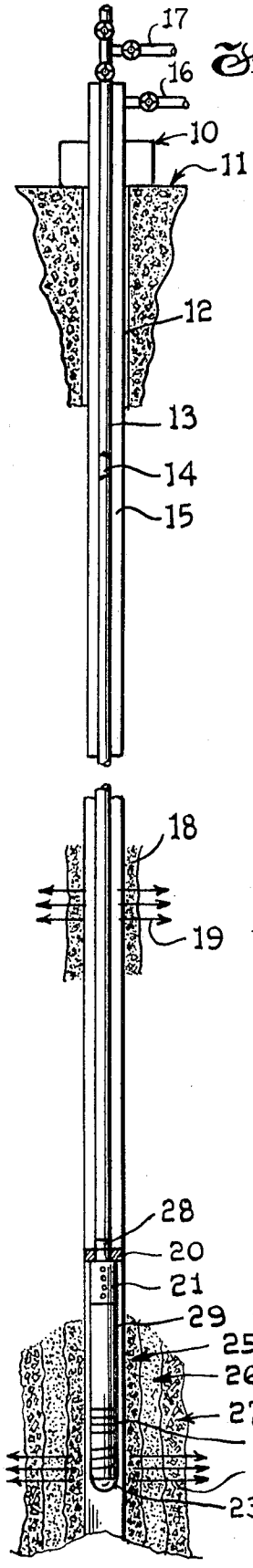

Fig. 2

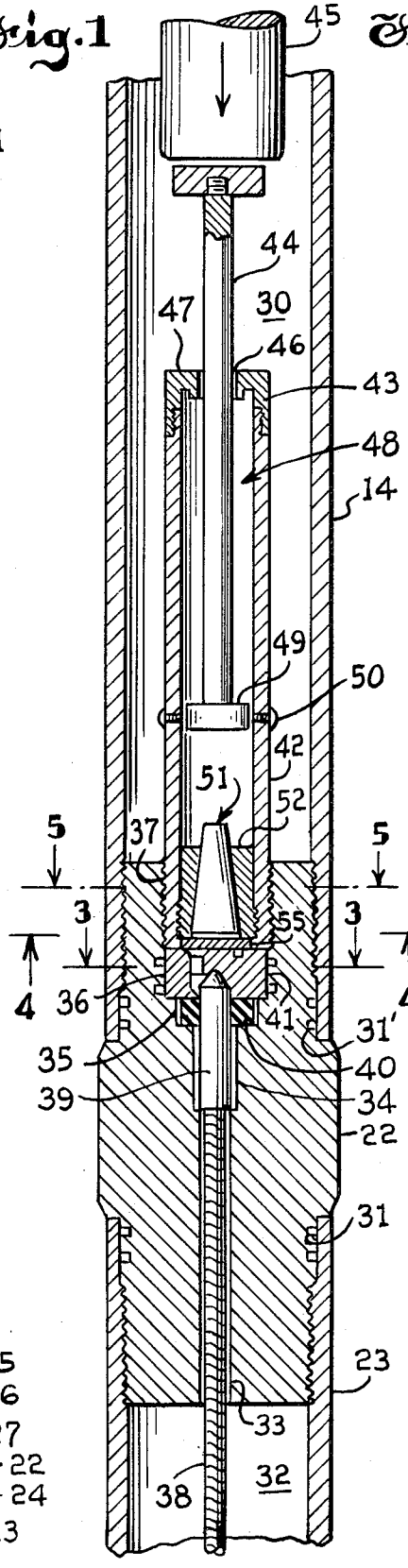

Fig. 3

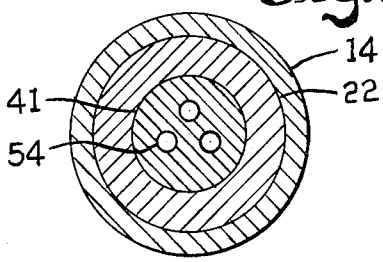

Fig. 4

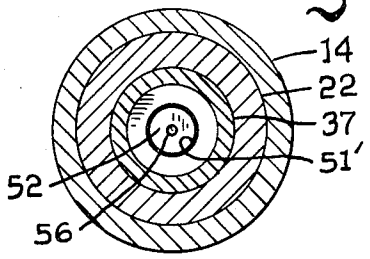

Fig. 5

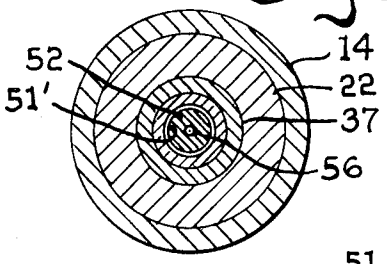

Fig. 6

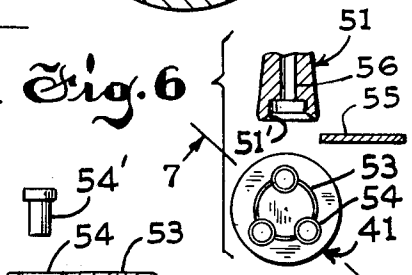

Fig. 7

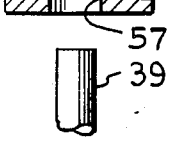

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Fig. 9

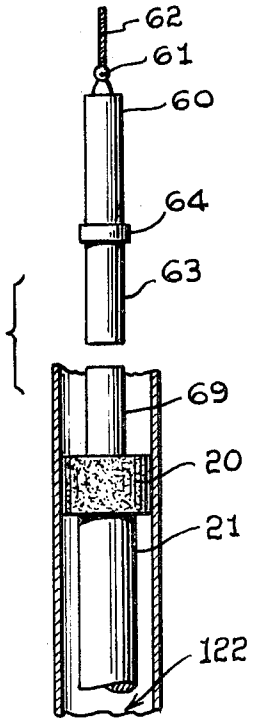

Fig. 10

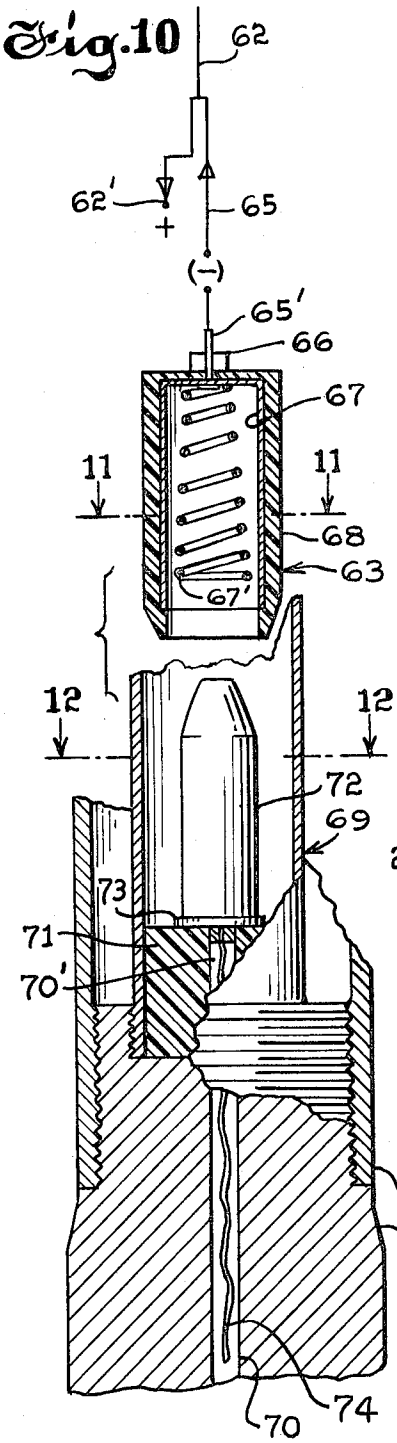

Fig. 8

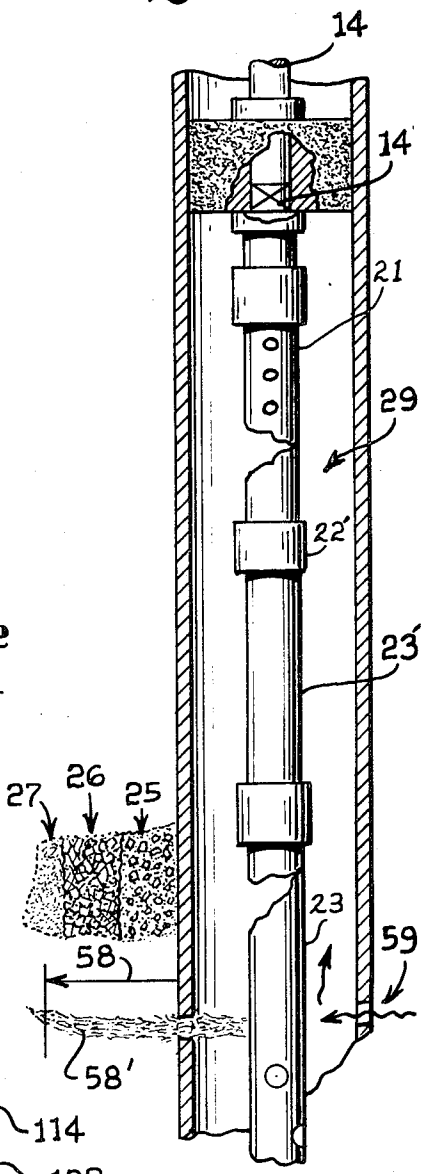

Fig. 11

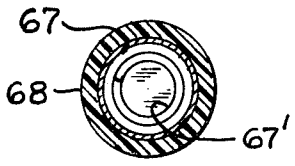

Fig. 12

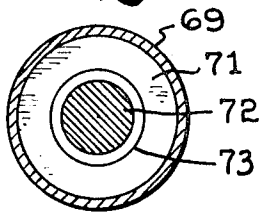

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Fig. 13

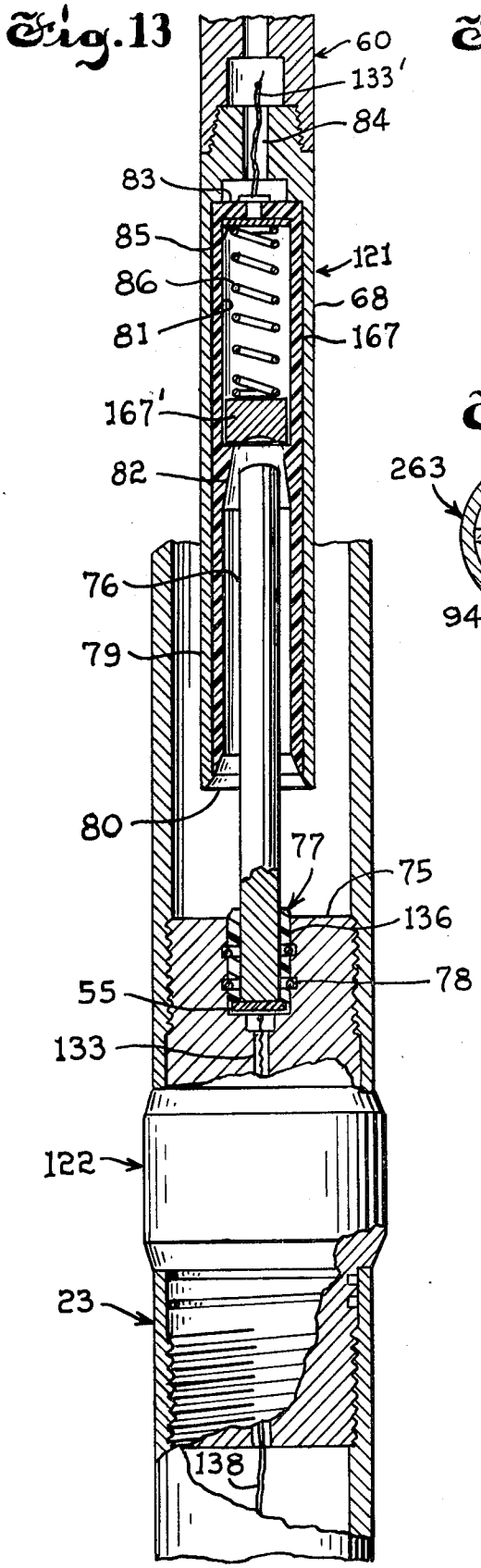


Fig. 14

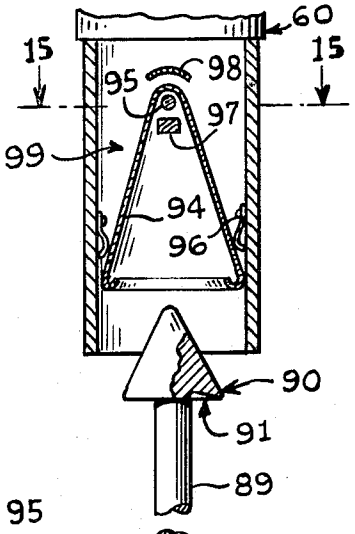
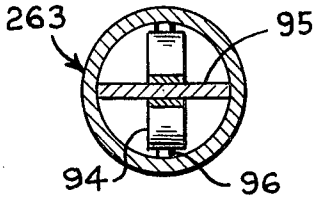
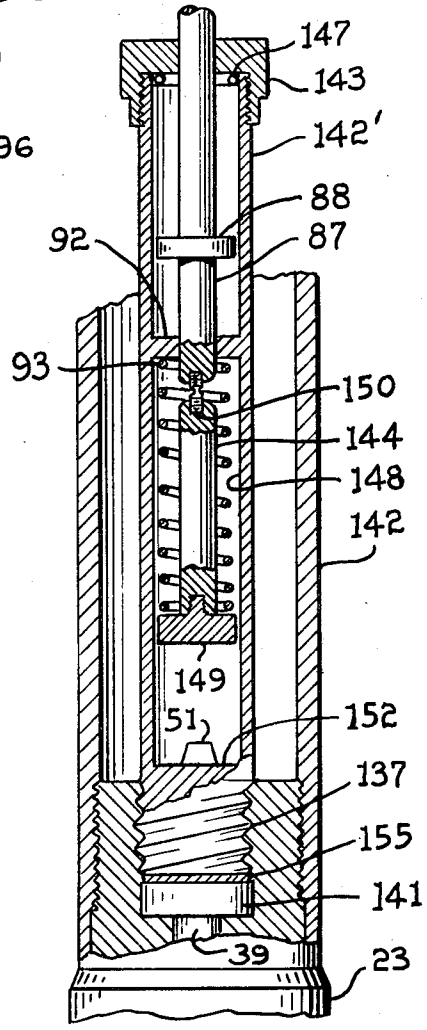


Fig. 15





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TUBING CONVEYED PERMANENT COMPLETION METHOD AND DEVICE

BACKGROUND OF THE INVENTION

There are several gas producing areas located in Eddy County New Mexico, as well as in other parts of the world, which contain production zones located at spaced apart elevations within a borehole. The lowermost gas producing formation of the Eddy County area is called the Morrow gas sand. The Morrow gas sand exhibits peculiarities which differ from most other gas sands known to Reservoir Engineers for the reason that this gas sand is easily contaminated upon being contacted with foreign organic and inorganic materials such as drilling mud, for example. Once contaminated, the Morrow gas sand has heretofore been rendered worthless, for economical production, in many cases.

In using prior art methods of completion, the lower zone, that is, the Morrow gas sand, is perforated whereupon the well is then "killed" and the upper zone perforated so as to enable subsequent production to occur from both zones. After the well has been completed and production simultaneously commences from both zones it has been found that production from the Morrow gas sand will fall from eight million to one-half million cubic feet per day. The loss in gas production cannot be regained, even though all known expedients of well treatment have been employed to effect such recovery.

Applicant believes that the reason for the Morrow gas sand exhibiting a rapid loss in production rate is because of contamination of the production formation immediately adjacent the borehole. That is, the Morrow gas sand, when contacted by foreign matter reverts to a low permeability sand which restricts the flow of gas therethrough. It is therefore desirable to be able to complete this valuable lower zone by utilizing completion methods which communicate a sterile portion of the Morrow sand or zone with the borehole, and to maintain the sterile formation in an uncontaminated condition.

It is also desirable to provide apparatus which enables such a method to be practiced.

SUMMARY OF THE INVENTION

This invention comprehends both the method and apparatus for completing one or a plurality of hydrocarbon producing formations by running a subsurface explosive and firing head into a borehole on the end of a production tubing with a packer being disposed in overlying relationship with respect to the explosive, which may be in the form of a large casing jet gun. The gun is left downhole isolated from the uncompleted upper zone. The upper zone is completed, production commenced, and then the well is optionally shut-in. The tubing is then again placed in communication with the packer and firing head of the gun, the tubing swabbed, the casing below the packer perforated, and production immediately commenced from the lower zone as soon as the perforations communicate the hydrocarbon producing formation with the production tubing. This expedient prevents contamination of the lower zone by enabling production to immediately occur upon formation of the casing perforations by the jet gun. Also much deeper penetration is made by this large gun than would be made by a conventional tubing gun. It also enables the upper zone to be produced simultaneously with the lower zone, thereby dual completing a well in a new and improved manner.

It is therefore a primary object of the present invention to provide both method and apparatus for completing a gas or oil well wherein the lower zone must be completed after the upper zone has been completed.

Another object of the present invention is the provision of method and apparatus for perforating a well casing adjacent to a lower hydrocarbon producing formation by using a tubing string through which the production of fluid occurs.

A further object of the present invention is the provision of method and apparatus for perforating the lower zone of a well while simultaneously producing from an upper hydrocarbon producing formation.

A still further object of the present invention is to provide a firing mechanism for detonating sub-surface explosives by the use of a weight which is passed through a production tubing from the surface of the earth by permitting the weight to free fall, or by lowering the weight on a small wireline, and producing through the production tubing, leaving the gun downhole.

Still another object of the present invention is to provide a wire line device for causing detonation of subsurface explosives by employing mechanical, electrical, or electro-mechanical devices.

These and other objects and advantages of this invention will become readily apparent to those skilled in the art upon reading the following detailed description and by referring to the accompanying drawings and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 diagrammatically sets forth the essence of the method of the present invention, and shows a cross-section of the earth's surface having a borehole formed therein, and additionally discloses apparatus fabricated in accordance with the present invention disposed therein;

FIG. 2 is an enlarged, fragmentary longitudinal cross-sectional view of part of the apparatus seen in FIG. 1;

FIGS. 3, 4, and 5, respectively, are cross-sectional views taken along lined 3—3, 4—4, and 5—5, respectively, of FIG. 2;

FIG. 6 is an isolated, part cross-sectional, disassembled view of part of the apparatus seen in the foregoing figures;

FIG. 7 is an enlarged cross-sectional view taken along line 7—7 of FIG. 6;

FIG. 8 is a schematical representation showing apparatus fabricated in accordance with the present invention as it may be used in a borehole in order to carry out the method of the present invention;

FIG. 9 is a diagrammatical representation of a modification of the foregoing embodiment;

FIG. 10 is an enlarged, fragmentary, part cross-sectional view of part of the apparatus disclosed in FIG. 9;

FIGS. 11 and 12, respectively, are cross-sectional views taken along lines 11—11 and 12—12, respectively, of FIG. 10;

FIG. 13 is an enlarged, fragmentary, part cross-sectional view of a modification of the apparatus seen in FIG. 10;

FIG. 14 is an enlarged, fragmentary, part cross-sectional view of a modification of the apparatus seen in FIG. 13; and

FIG. 15 is a cross-sectional view taken along line 15—15 of FIG. 14.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

As seen in FIG. 1, a well head 10 is situated above the ground 11 in the usual manner, and is provided with a casing 12 through which production tubing 13 is axially disposed, thereby forming an inner flow path 14 and an annular flow path 15, as is known to those skilled in the art of completing gas wells having several production zones.

Outlet 16 is adapted to be connected to the upper production zone, with each of the outlets being provided with suitable valves and the like, which cooperate to form the usual Christmas tree.

Generally, cement will be disposed about the casing adjacent a production formation as indicated by the arrow at numeral 18, bringing about the necessity of a perforator means having a capacity of penetrating both the casing and the cement in order to form passageways from the production formation to thereby enable hydrocarbons to flow into the annulus, to the outlet, and to a suitable gathering system.

Packer 20 can take on several forms; but, by way of exemplification is preferably a commercially available Baker retrievable casing packer, and hence the packer can be repositioned within the bore-hole merely by "-setting down" or "picking up" on the packer by using the tubing string 13. Perforated nipple 21 underlies the packer and is connected to a gun firing mechanism 22 which is herein disclosed as taking on several different forms. The perforated nipple can be of any desired length and can be provided with as many apertures as deemed desirable. The gun firing mechanism causes the shaped charges of the casing gun 23 to "fire" when it is properly activated.

While a casing gun is used herein by way of example, it should be understood that the term is intended to include any means for communicating a hydrocarbon producing formation with the well bore. The jet perforator gun, which is of the casing perforator type penetrates deeply into the adjacent surroundings for as much as 20 inches, which a through tubing gun cannot do, of course. The formation openings caused by the action of the hot bi-metallic gases of the jet perforator is illustrated by the arrows at numeral 24. Numeral 25 indicates hydraulic cement which circumferentially surrounds the casing and is about two inches or more in thickness. Numeral 26 is a schematical representation of a contaminated production zone of the Morrow formation, while numeral 27 indicates the surrounding sterile zone of the Morrow formation.

The packer is connected to the inner tubing by a connection 28 which enables the tubing to be removed therefrom and a plug substituted therefor, and vice versa, from surface manipulation of the tubing. This expedient is well known to those skilled in the art. Numeral 29 indicates the lower casing annulus.

Looking now to the remaining figures, in conjunction with FIG. 1, the gun firing mechanism is seen to be comprised of a firing head 22 which joins a casing jet perforator mechanism 23 to the lower extremity of tubing 14. O-rings 31, 31' preclude flow of fluid into the diametrically opposed threaded ends. The interior of the jet perforating gun is provided with an axial counterbore 33 which enlarges into a second counterbore 34 of limited length, which again enlarges into still another counterbore at 36, thereby forming an axial passageway which extends longitudinally through the head. The outer marginal inside peripheral surface of the last counterbore is provided with a threaded surface at 37.

Primer cord 38, which is an unsensitive explosive and known to those skilled in the art, is suitably affixed to a primer cord detonator 39 in the usual manner. The detonator resembles a blasting cap and has a hollow end portion which receives the upper marginal terminal end portion of the primer cord. The cap is sealingly secured within a resilient waffer 40 with the waffer being compressed by the primary detonator assembly 41. The primary detonator assembly detonates the detonator 39 which explodes the primer cord which in turn activates the shaped charges of the jet perforating gun. The details of the gun are well known to those skilled in the art, and can take on several different forms.

Upstanding cylinder 42 is threadedly provided with a cap 43, with the cap being apertured at 46 to loosely and slidably receive a mandrel in the form of a shaft 44 therethrough. A weight 45 is seen about to impound upon the enlargement which forms the free terminal end of shaft 44.

Seal means 47 is placed to avoid hermetically sealing the interior 48 of the cylinder. Enlargement 49 is rigidly affixed to shaft 44 and is secured against movement by the provision of a series of radially spaced apart brass shear pins 50 which can be in the form of a common brass screw.

Tapered firing pin 51 is in the form of a frusto cone and is captured within holder 52. The holder is provided with a circumferentially extending groove 53 which can receive the lower marginal end portion of downwardly projecting skirt 51' of the firing pin therein. Equally spaced apart from one another and intersecting the groove there is provided three drilled recesses 54 each of which receives a 22 caliber primer 54' therein. A thin copper waffer 55 is compressed between the terminal end of the holder and assembly 41 and acts as a gasket.

An axial passageway 56 is formed within the firing pin. Drilled counterbore 57 intersects each counterbore 54. The lower marginal end of counterbore 57 receives a marginal free end portion of the before mentioned detonator therein in safe but close fitting relationship.

As best seen in FIG. 8 the lower tubing can be isolated by a plug 14' and the tubing string removed from the packer so as to enable completion of the upper hydrocarbon producing formation without danger of falling debris or inadvertent firing of the gun.

Numeral 58 is a hypothetical illustration of the effective distance which the hot sterile bi-metallic jet of gases 58' from the shaped charge are able to penetrate into the surrounding formation, thereby leaving the casing apertured as seen at 59.

Looking now to the details of FIG. 9, the nipple 21 is disclosed as being attached to a gun firing head 122,

and to a packer from which there upwardly depends for a limited distance an electrical receptacle **69**. A gamma ray tool **60** is attached at **61** to a wire line **62** having a conductor therein. Electrical contacting member **63** underlies the gamma ray device and is series connected to a diode which passes (−) current flow. The gamma ray tool must be connected to a (+) current flow because of the diode in conductor **62'**.

As seen in FIG. **10** the member **63** is cylindrical in form and includes insulator **68** having a cylindrical copper lining **67** therein. The conductor **65'** is attached to the lining by connector **66**. Coil spring **67'** is electrically connected to the lining by means of its terminal end adjacent connector **66**.

Member **63** is telescopingly received within upstanding cylinder **69**. Passageway **70**, formed in head **122**, communicates with passageway **70'**. To the head there is attached an insulator **71** which rigidly supports metallic electrode **72**. Contact base **73** is electrically connected to conductor **74** so that when member **63** is telescopingly received within cylinder **69** electrode **72** will engage the interior of spring **67'** thereby completing the circuit from **62, 65, 65', 67', 72, 73**, and to conductor **74**. The flow of current at **74** fires an electrically actuated perforating gun located below gun head **122**. The details of electrically actuated perforating guns are known to those skilled in the perforating art.

Throughout the remaining figures, wherever possible, like or similar numerals will refer to like or similar parts.

Looking now to the details of FIG. **13** which illustrates a modification of the apparatus seen in FIG. **10**, the before mentioned gamma ray tool **60** is seen to be attached to an elongated hollow cylindrical member **121** which can be run into the hole on a wire line in the same manner as described in conjunction with the apparatus seen in FIGS. **9** and **10**.

Gun head **75** is provided with an axial passageway **133** which enlarges into counterbore **55'** so as to receive a metallic electrode **76** therein. Epoxy cement is placed within annulus **77** so as to rigidly secure the electrode to the sub. The spaced apart O-rings **78** maintain the electrode centrally located within the gun head prior to applying the epoxy.

The electrical probe includes a downwardly opening metallic skirt member **79** having a lower depending circumferentially extending sloped edge portion at **80** within which there is disposed a plastic liner **81** which insulates the entire inside peripheral wall surface of the probe. As seen at numeral **82**, the liner converges inwardly and upwardly so as to form a shoulder or stop means. A copper cylindrical plug **167'** abuts against the illustrated shoulder. The upper extremity of the insulation member is provided with a closure member **83**. Wires **133** are received through passageway **84** and electrically connected to a source of electrical current within the gamma ray device.

It should be understood that a power supply attached to a slick line can be substituted for the gamma ray tool, or that the probe can be directly attached to a wire line with the wire line being directly connected to a source of current located above the bore-hole.

Contact **85** is rigidly affixed to the insulator and electrically connected to wires **133** so as to form a wall against which biasing spring **86** can be received so as to urge the plug in a downward direction. Hence it can be seen that plug **167'** can be reciprocated within the upper chamber as it is contacted by the electrode.

FIG. **14** illustrates a modification of the foregoing embodiments, wherein a gun sub **23**, which is identical to the sub of FIG. **2**, receives a primary detonator assembly **141** therein, with a copper waffer **155** being interposed therebetween, and with the firing pin **51** being disposed within holder **152** in the same before described manner of FIG. **2**.

Upper shaft portion **87** has an intermediate enlargement **88** slidably received thereon and connected thereto by a sheer pin (not shown) which is sheared when the shaft is subjected to a pull or upward force of two hundred pounds. The shaft slidably depends from a central aperture located in a cap **143** as indicated by numeral **89**, where the upper free end of the shaft is formed into a cone **90** having a circumferentially extending inwardly and upwardly sloped portion **91**.

Inwardly directed stop means **92** has opposed shoulders formed thereon to form an upper face against which enlargement **88** abuts; and a lower face against which spring **93** is compressed. The remaining end of the spring is compressed against the illustrated enlargement **149** with the enlargement normally being spaced apart from the firing pin when the intermediate enlargement **88** abuts the stop means, the latter position being the stand-by configuration. Moreover, enlargement **88** will not abut the cap **143** before the enlargement **149** fully compresses the spring. Hence the pin **150** must shear in order for the enlargement **88** to reciprocate into abutment with the cap.

Shear pin **150** has an undercut mid-portion adapted to shear at **100** pounds tensile strength. The spring must reach a compressive force of this value prior to the enlargement reaching the cap. The pin connects shaft portion **89** to shaft portion **144**.

In order to actuate the gun firing mechanism, it is necessary to apply sufficient force to conical member **90** so as to shear pin **150**. The hollow cylindrical member **263** has an inside diameter which permits the bifurcated member **94** to be engaged with and latched onto the cone. Member **94** has sprung apart legs which are bent about support pin **95** with the support pin having opposed end portions attached to the inside peripheral wall of housing **263**. Curved member **98** is welded to the side walls of the cylinder and overlies the bent portion of the spaced apart legs so as to form an upper stop means, while stop member **97** precludes damage to the legs should the tool over-run the cone. Hence, the spaced apart legs are guidably captured within the chamber **99**.

OPERATION

In operation, after the borehole has been formed, and the casing cemented into place at **18** and **25**, with the latter two numerals also indicating that the surrounding area is in a production zone with the production zones being spaced apart by perhaps several thousand feet, it is necessary to perforate the casing adjacent each of the production zones so as to allow the gas or oil to flow into the borehole and to the surface of the ground. For many reasons it is necessary to maintain the flow from each of the two gas or oil producing formations separated from one another. In order to ac-

complish this requirement a packer **20** and production tubing **14** are disposed within the well so that production from each formation may ultimately be brought to the surface of the ground as two isolated flow streams with production from the completed upper zone outflowing at **16** and production from the completed lower zone outflowing at **17**.

The gas pressure at formation **27** is of the order of **5–10** thousand p.s.i. In normal operations the lower zone would be perforated, tested, and the well killed. The upper zone would then be completed. However, this expedient would destroy the lower zone if the underlying production formation should exhibit the same phenomena as the Morrow sand. Accordingly, at the instant the Morrow gas sand is completed, it is absolutely essential that the shaped charge effect an opening which extends radially past the contaminated portion of the sand, out into the sterile sand, and that the 5,000 p.s.i. pressure differential enable immediate flow to occur from the sterile sand, through the contaminated sand, through the cement and casing perforations, into the casing annulus, through the perforated nipple, up through the inner tubing, to where the well is free flowed at **17** by producing the gaseous products until the lower borehole is absolutely clean and the well can be connected into a gathering system.

This is accomplished by running the packer, gun firing mechanism, and deep penetrating casing jet gun into the hole on the bottom of the production tubing. Hence the apparatus is a tubing conveyed permanent completion device, for it must remain in the borehole.

Before running the packer and gun downhole, the borehole is swabbed dry. Gamma ray and collar locator is used before setting the packer so as to exactly or ideally position the gun where it will fire into the optimum portion of the formation.

The packer, perforated nipple, gun firing mechanism, and casing gun are positioned within the borehole. The tubing below the retrievable packer is plugged, the tubing above the packer moved, and the packer along with the perforated nipple, gun, and firing mechanism left in the hole in stand-by configuration while the upper zone is completed using conventional methods. After the upper zone has been completed, tested, and perhaps shut-in, the tubing is replaced, swabbed dry, the plug removed, and the jet gun is fired. The upper zone may be on production at this time if desired.

Where the embodiment of FIG. **2** is used to fire the gun, the weight, which may be free falling or attached to a slick-line, strikes the end of shaft **44** causing shear pin **50** to rupture, and the enlargement **49** to strike the upper terminal end of the firing pin, driving the lower end of the pin through the copper disk and into the three rim fire cartridges. The cartridges explode, raising the pressure within chamber **57** to a value which activates the detonator. The detonator "sets off" the primer cord, which in turn "fires" each of the shaped charges within gun **23**.

The deep jets of hot bi-metallic sterile gases effect a passageway into the uncontaminated Morrow sand, thereby communicating the sterile gas zone with the casing annulus, whereupon production can instantaneously occur along the before described flow path. The gun firing mechanism and jet gun are left downhole to form the bull plug. Since an excellent gas well has been made, the value of the gun and firing mechanism is of little comparative value. Where deemed desirable, a tubing cutter can be run through the tubing and everything below the perforated nipple dropped to the bottom of the hole.

The above method avoids contacting the Morrow sand with any contaminate whatsoever, and since the formation is immediately open flowed, it will continue to produce at a maximum rate.

In operation of the embodiment of FIGS. **9** and **10**, a gamma ray tool having the probe attached thereto is lowered through tubing **14** until gun firing electrode **72** comes into electrical contact with either spring **67'** or copper liner **67**. The wire line **62** must be changed from (+) to (−) polarity in order to enable current to flow from **62'** to **65'**. The gamma ray device normally operates on (+) current flow.

Current is conducted from **72** along conductor **74** to a blasting cap (not shown) located in the lower extremity of the casing gun. The cap detonates a primer cord which in turn detonates each of the shaped charges.

In operation of FIG. **13**, should the gamma ray tool inadvertently over run whereupon the electrode **76** prematurely contacts the slug **167'**, the detonator will not be activated because current cannot flow from **62** to conductor **65** because it will be of improper polarity for proper actuation of the gun since it was previously of the necessary polarity to enable it to be used in conjunction with the gamma ray device. Accordingly, the polarity must be reversed, the probe run downhole into the position seen in FIG. **13**, whereupon the lower edge portion of the skirt will receive the electrode therein. As the probe is further lowered, the electrode contacts the copper slug, with further lowering of the probe causing the slug to reciprocate within its chamber. This action completes the circuit which can be traced from conductor **133'**, washer **85**, spring **86**, into the slug where contact is made with the upper free end portion of the electrode, whereupon current then flows into washer **55'**, conductor **138**, and to the lowermost portion of the jet gun where an electric cap is fired. The cap detonates the primer cord which in turn commences sequential detonation of the spaced apart shaped charges. As soon as the gun has been fired, production commences. It is essential that the gamma ray device be left below the perforated nipple where it is isolated from the high velocity upwardly flowing production fluid or otherwise the probe and gamma ray device would be forced up through the production tubing along with the gaseous hydrocarbons as they race to the surface of the earth.

Where deemed desirable, the chamber above gun head **75** can be filled with a liquid insulator which is non-conductive and which has a specific gravity greater than brine so as to maintain the conductance between electrode **76** and the production tubing at a minimum. Such an expedient, while being desirable, is not absolutely essential for the reason that sufficient electrical energy may be applied to the electrode to thereby form two different current flow paths, with one flow path being through the liquid which surrounds the electrode and the other flow path being to conductor **138**. Hence the magnitude of the current imposed at **133'** will

determine when the gun fires, regardless of the conductance of the liquid medium which surrounds the electrode.

In the embodiment of FIG. 14, the enlargement 88 normally abuts its associate stop means, with the enlargement 149 being spaced apart from the firing pin. Hence, should an object be inadvertently contacted with or impacted against the cone member, firing of the gun will be avoided. When it is desired to actuate the gun, cylindrical member 263 is run downhole together with a power source by using a slick-line, or in conjunction with a gamma ray device and a wire-line, or a wire-line alone. As the cone is received within the downwardly depending skirt member, the inwardly turned depending ends of spring 94 will be forced outward over the cone and into the circumferential groove 91 thereby locking member 263 to the cone. Should the wire-line tool over-run the cone, it will abut stop 97 and avoid damage to the bifurcated member 94. Should the wire-line or the slick-line be rotating during contact, springs 96 maintain alignment between legs 94 and the cylinder. Tension is applied to the wire-line, a strain gauge observed to assure that shaft 89 is being withdrawn from cylinder 142', and as tension is increased on the wire-line it will soon exceed the tensile strength of shear pin 150. As the shaft is withdrawn from the cylinder, spring 93 is compressed, thereby spring loading abutment 149 and lower shaft portion 144. As pin 150 shears, abutment 149 accelerates toward and contacts firing pin 51 whereupon the firing pin penetrates the copper waffer 155 and strikes the cartridges located within member 141 to thereby detonate cap 39 which in turn detonates the primer cord attached thereto. This action explodes the shaped charges in the before described manner of FIG. 2.

The present method of running a sub-surface explosive into a borehole on the end of a tubing string with a packer disposed above the explosive device has several unexpected added advantages. For example, a 72 hour recording device, such as a pressure bomb, can be placed below the perforated nipple by suspending the bomb from the same wire-line which actuates the gun firing mechanism. This expedient enables bottom hole pressure to be monitored from the instant the perforations are made, and for 72 hours thereafter. Data of this nature has never before been attained.

The present invention can also be used to advantage in formations other than the Morrow type where it is desired to save operating time in carrying out fracturing or acidizing processes. In this instance, after the packer is set, acid is spotted in the bore-hole by pumping it down the tubing string, through the perforated nipple, and into proximity of the zone to be treated. The gun is fired in the before described manner, additional fluid pumped into the hole, and the tubing swabbed back, if necessary. Hence, the unexpected advantage of making a single trip into the well to spot the acid prior to perforating is realized. Moreover, the ability to apply fracturing pressures at the moment of forming the perforations is believed unique and is believed to offer a new means by which the acid can be forced into the fissures or perforations, it being noted that the formation is simultaneously subjected to the borehole hydrostatic head, the pressure from the pump, and the explosive shock of the shaped charges.

The present method can also be used to plug a well in a single trip by substituting a casing cutter for the perforating gun. The gun firing mechanism is actuated in the before described manner, the casing is severed, and the cement pumped through the perforated nipple and deposited in the top of the remaining stub. The tubing is then withdrawn from the borehole, thereby eliminating the requirement of a wire-line unit, and enabling the entire plugging operation to be effected in a single trip.

While a single perforated nipple is disclosed herein, and a single perforating means referred to, it must be understood that several nipples may be series connected in order to present an essentially unrestricted flow path from the lower casing annulus into the interior of the tubing string. The use of several series connected guns in order to perforate several spaced apart "stringers" or production zones is considered to be within the comprehension of this invention.

Those skilled in the art, having digested this disclosure, will now envision the elimination of the perforated nipple and the use of the interior of the gun and gun firing mechanism in order to provide a flow path into the tubing string, with the flow path being formed after the sub-surface explosion occurs, and accordingly, such a variation or modification is considered to fall within the metes and bounds of this disclosure. Moreover, it is anticipated to use this method in order to complete single, dual, and tripple completed wells since it is now within the comprehension of those skilled in the art to extend the teaching of the present invention to include such completion methods.

Where it is desired to seal off the gun at a location below the perforated nipple so as to possibly preclude the upflow of debris therefrom, a second seating nipple can be installed above the gun firing head, and a slick-line having a mandrel thereon can pick up the plug at 14', travel down to the gunhead and actuate the subsurface explosive, and thereafter seat the plug in the lower nipple.

The present method can also be used in boreholes which have no casing located at the lower extremity thereof, there being many wells of this nature which can be revived by utilizing the teachings set forth herein.

I claim:

1. The method of completing a lower hydrocarbon zone of a well after an upper hydrocarbon zone has been completed, comprising the steps of:

1. suspending a packer and a casing perforator means on the end of a tubing string with the perforator means being placed in underlying relationship relative to the packer;
2. positioning the packer downhole by using the tubing string in a manner to dispose the perforator adjacent to the lower hydrocarbon zone;
3. forming a fluid flow path from below the packer which communicates the interior of the casing with the interior of the tubing string;
4. completing the upper zone;
5. completing the lower zone by actuating the perforator means;
6. leaving the perforator means downhole and producing the lower zone through the tubing string and producing the upper zone through the upper casing annulus.

2. Method of claim 1 wherein step (3) is carried out by interposing a perforated nipple between the perforator means and the packer.

3. The method of claim 1, wherein the well is open flowed the instant the perforations are formed to thereby avoid contamination of the hydrocarbon bearing formation.

4. Method of claim 1 wherein the perforator means is a deep penetrating shaped charge which is placed adjacent the casing wall so as to enable a deep penetration to be effected into the hydrocarbon bearing zone.

5. The method of claim 4 wherein the shaped charge is detonated in response to apparatus which is disposed through the tubing string.

6. The method set forth in claim 4, wherein the shaped charge is electrically fired by running a means having a source of electrical current therein through the tubing interior and to the perforator means on a wire-line.

7. In a well having a borehole which extends downhole through an upper and a lower hydrocarbon containing zone, with each zone having at least one hydrocarbon containing formation, with the lower zone being isolated from the interior of the borehole by a well casing or the like, the method of completing the lower zone of the well after the upper zone has been completed comprising the steps of:

1. suspending a casing perforator means and a packer means from a tubing string;
2. setting the packer means downhole in the borehole at a location which positions the perforator means adjacent to at least one hydrocarbon containing formation of the lower hydrocarbon containing zone, while at the same time isolating the portion of the borehole underlying the packer means from the portion of the borehole located above the packer means;
3. forming an unobstructed flow path which extends from the borehole annulus underlying the packer means, into the tubing string, and uphole to the top of the borehole;
4. actuating the casing perforator means so as to perforate the casing and to communicate the hydrocarbon containing formation of the lower zone with the borehole annulus underlying the packer means to thereby enable production from the last named formation to flow through the perforations, into the lower borehole annulus underlying the packer means, into and up through the tubing string, and to the top of the bore-hole.

8. The method of claim 7 wherein step (2) is carried out by running a gamma ray and collar locator through the tubing on a wire line so as to enable a gamma ray log to be obtained and indexed with an open hole log whereupon the gun can be positioned adjacent to a formation indicated on the open hole log.

9. The method of claim 7 wherein step (3) is carried out by interposing a perforated nipple between the perforator means and the packer, and by removing essentially all of any liquid which may be present in the tubing string above the packer means so as to provide a hydrostatic head which is essentially zero at the hydrocarbon containing formation.

10. The method of claim 7, and further including the step of reducing the hydrostatic head within the tubing string to essentially zero prior to carrying out step (4).

11. In an oil well having a well bore which penetrates an upper and a lower hydrocarbon containing formation, the method of completing the lower hydrocarbon containing formation after the upper hydrocarbon containing formation has been completed so that fluid from the upper completed formation is prevented from contaminating the lower hydrocarbon containing formation while it is being completed, comprising the steps of:

1. suspending a sub-surface explosive means and a packer means from a tubing string;
2. setting the packer means within the borehole at a position which isolates a lower portion of the borehole containing the lower hydrocarbon containing formation from an upper portion of the borehole containing the upper completed hydrocarbon containing formation; and which positions the explosive means adjacent to the lower hydrocarbon containing formation;
3. forming a flow path which communicates the lower borehole annulus with the interior of the tubing string;
4. reducing the hydrostatic head within the tubing string to essentially zero at the packer means;
5. using the interior of the tubing string as a passageway through which the explosive means is actuated, so as to communicate the lower borehole annulus with the lower hydrocarbon containing formation;
6. producing fluid from the lower hydrocarbon containing formation by flowing the fluid along the flow path set forth in step (3); and
7. producing fluid from the upper hydrocarbon containing formation by flowing the fluid up the upper borehole annulus.

12. The method of claim 11 wherein step (2) is carried out by running a gamma ray and collar locator through the tubing on a wire line to enable a gamma ray log to be obtained and subsequently indexed with an open hole log.

13. The method of claim 11, wherein step (3) is carried out by interposing a perforated nipple between the packer and the explosive means.

14. The method of claim 13, wherein the nipple and any remaining explosive means is left downhole after completing the well.

15. In a borehole which extends into proximity of a production zone, the method of completing a well comprising the steps of:

1. suspending a sub-surface perforating means and a packer means from a tubing string;
2. setting the packer means within the borehole at a position which enables the packer means to isolate a lower portion of the borehole from an upper portion of the borehole and which positions the perforating means adjacent to the production zone;
3. forming a flow path which communicates the lower portion of the borehole with the interior of the tubing string;
4. using the interior of the tubing string as a passageway through which the perforating means is caused to be actuated so as to communicate the interior of the borehole which underlies the packer means with the production zone;

5. producing the production zone along the flow path of step (3) immediately upon carrying out step (4) and,

6. severing the perforating means from the packer means to permit any remaining part of the perforating means to drop to the bottom of the borehole after the well has been completed.

16. Apparatus for completing a production zone of a well bore, comprising, in combination:

a tool string which includes a packer means, a production tubing, an explosive perforating gun means which is larger in overall diameter than said tubing; a gun firing head, and a perforated nipple;

said gun means being attached to and underlying said gun firing head, said gun firing head being attached to and underlying said perforated nipple, said perforated nipple being attached to and underlying said packer means, said tubing being connected to said packer means to thereby enable the tubing to position the packer means within the well bore so as to suspend the gun means adjacent to a production zone;

a plug means which can be removably placed within said tool string so as to isolate the perforated nipple from the interior of the production tubing; means by which the tubing can be removably affixed to said packer means, and, means for actuating said gun head when the last said means is lowered through the interior of the tubing string and into contact with said gun head when the production tubing is attached to the packer;

said gun head including opposed ends, and means forming a longitudinally extending passageway therethrough; one said opposed end adapted to be connected to said gun means and the remaining said opposed end adapted to be connected to the perforated nipple for supporting the gun means and the gun head in the before recited manner;

a detonator, a primary detonator assembly adapted to cause said detonator to explode when said primary detonator is exploded, and a firing pin holder; said passageway including a chamber for holding said detonator, said primary detonator assembly, and said firing pin holder therein; means including a firing pin reciprocatingly received within said firing pin holder and superimposed over at least part of said primary detonator so as to enable part of said firing pin to strike a part of said primary detonator thereby exploding said primary detonator when said firing pin is moved within said pin holder by said means for actuating said gun head; means connected to said detonator for causing said gun to be actuated when the detonator is exploded; whereby:

the gun means can be isolated by the plug from the portion of the borehole laying above the packer, and the tubing string can be removed from the packer means to thereby enable the borehole above the packer means to be entered, and thereafter the tubing string can be replaced, the plug means removed, and the production zone completed by actuating the gun.

17. The apparatus of claim 16, wherein said means for actuating said gun head is a mass which is dropped through the interior of the tubing string so as to enable the mass to strike and move said firing pin.

18. The apparatus of claim 16 wherein said means for actuating said gun head includes means forming a spring loaded mandrel, wire-line means for biasing said mandrel against said spring, and means for releasing said mandrel to thereby enable the biased mandrel to strike and move the firing pin.

19. The method of completing an oil well wherein an upper and a lower hydrocarbon formation has been penetrated by a cased well bore, and wherein the upper zone has been completed and placed in production, comprising the steps of:

1. suspending a packer and a casing perforator means on the end of a tubing string with the perforator means being placed in underlying relationship relative to the packer;
2. positioning the packer downhole by using the tubing string in a manner to dispose the perforator means at a location adjacent to the lower hydrocarbon zone, and to isolate the upper borehole annulus which penetrates the upper hydrocarbon formation from the lower borehole annulus which penetrates the lower hydrocarbon formation, thereby preventing any production from flowing from the upper hydrocarbon formation into the lower borehole annulus;
3. forming a fluid flow path which extends from the lower borehole annulus, into the interior of the tubing string, and up the interior of the tubing string to the surface of the ground;
4. completing the lower hydrocarbon formation by actuating the perforator means of step (1);
5. leaving the perforator means downhole and producing the lower zone through the tubing string and producing the upper zone through the upper casing annulus.

20. The method of claim 19 wherein the well is open flowed the instant communication between the lower zone and the borehole annulus is effected to thereby avoid contamination of the hydrocarbon bearing formation.

21. The method of claim 19 wherein step (2) is carried out by running a gamma ray and collar locator through the tubing on a wire line so as to enable a gamma ray log to be obtained and subsequently indexed with an open hole log.

22. The method of claim 19 wherein step (4) is carried out by using a deep penetrating shaped charge which is placed adjacent the casing wall so as to enable a deep penetration to be effected into the lower hydrocarbon bearing zone.

23. The method of claim 22 wherein the shaped charge is detonated in response to electrical apparatus which is lowered through the tubing string.

24. The method set forth in claim 22, wherein the shaped charge is electrically fired by running a means having a source of electrical current therein through the tubing interior and to the perforator means on a wire-line.

25. In a well having a borehole which extends downhole through a production zone having at least one hydrocarbon containing formation, with the zone being isolated from the interior of the borehole by a well casing or the like, the method of completing the well comprising the steps of:

suspending a casing perforator means and a packer means from a tubing string;

setting the packer means downhole in the borehole at a location which positions the perforator means adjacent to at least one hydrocarbon containing formation, while at the same time isolating the portion of the borehole underlying the packer means from the portion of the borehole located above the packer means;

forming an unobstructed flow path which extends from the portion of the borehole underlying the packer means, into the tubing string, and uphole to the top of the borehole;

plugging the passageway so as to prevent flow of fluid through the packer means; removing the tubing string above the packer means so as to gain unobstructed access to the portion of the borehole above the packer means; replacing the tubing string above the packer; removing essentially all of the fluid from the tubing string, so as to reduce the pressure differential across the formation to a minimum value, unplugging the passageway; and,

actuating the casing perforator means so as to perforate the casing and to communicate the hydrocarbon producing formation with the portion of the borehole underlying the packer means, so that produced fluid can flow into and up through the tubing string, and to the top of the borehole.

26. In a well having a borehole which extends downhole through a production zone having at least one hydrocarbon containing formation, with the zone being isolated from the interior of the borehole by a well casing or the like, the method of completing the well comprising the steps of:

1. suspending a casing perforator means and a packer means from a tubing string;
2. setting the packer means downhole in the borehole at a location which positions the perforator means adjacent to at least one hydrocarbon containing formation, while at the same time isolating the portion of the borehole underlying the packer means from the portion of the borehole located above the packer means;
3. forming an unobstructed flow path which extends from the portion of the borehole underlying the packer means, into the tubing string, and uphole to the top of the borehole;
4. plugging the passageway below the tubing string;
5. removing the tubing string;
6. completing an upper zone of the well;
7. replacing the tubing string;
8. removing essentially all of the liquid from the tubing string;
9. unplugging the passageway; and,
10. actuating the casing perforator means so as to perforate the casing and to communicate the hydrocarbon producing formation with the portion of the borehole underlying the packer means, thereby enabling flow to occur into and up through the tubing string, and to the top of the borehole.

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,706,344 Dated DECEMBER 19, 1972

Inventor(s) ROY R. VANN

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Correct the Inventor's address as follows:
--[72] Inventor: ROY R. VANN
BOX 40-A STAR ROUTE WEST
ARTESIA, NEW MEXICO 88210 --.

Column 13, line 56, after "plug" insert --means--.

Column 15, line 17, after "packer" insert --means--.

Signed and sealed this 3rd day of July 1973.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

Rene Tegtmeyer
Acting Commissioner of Patents

FORM PO-1050 (10-69)

USCOMM-DC 60376-P69
* U.S. GOVERNMENT PRINTING OFFICE : 1969 O—366-334.

REEXAMINATION CERTIFICATE (362nd)

United States Patent [19] [11] **B1 3,706,344**

Vann [45] Certificate Issued **Jul. 9, 1985**

[54] **TUBING CONVEYED PERMANENT COMPLETION METHOD AND DEVICE**

[76] Inventor: **Roy R. Vann**, 3302 Providence Dr., Midland, Tex. 79701

Reexamination Request:
No. 90/000,471, Nov. 25, 1983

Reexamination Certificate for:

Patent No.:	**3,706,344**
Issued:	**Dec. 19, 1972**
Appl. No.:	**80,991**
Filed:	**Oct. 15, 1970**

Certificate of Correction issued Jul. 3, 1973.

[51] **Int. Cl.**[3] **E21B 43/116**; E21B 43/12; E21B 43/14

[52] **U.S. Cl.** **166/297**; 166/55; 166/250; 166/313; 175/4.52; 175/4.56; 175/4.6

[58] **Field of Search** 166/313, 55, 254, 370, 166/297; 175/4.56, 4.6

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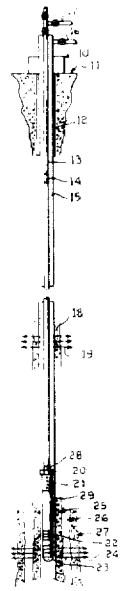
Primary Examiner—Stephen J. Novosad

[57] **ABSTRACT**

Method and apparatus for effecting a dual completed well wherein the lower zone is packed off or isolated from the upper zone prior to perforating either zone; the upper zone is then completed, whereafter the lower zone is perforated. In perforating the lower zone a casing perforating gun, gun firing mechanism, and packer are run into the hole with the gun being suspended below the packer and properly positioned with respect to the borehole. The lower zone is then isolated and the tubing to the packer is removed. The upper zone is then completed, tested, and shut-in, if desired. The tubing is again flow connected to the packer, swabbed clean, and then the casing perforator is actuated, with the production from the lower zone being free to flow to the surface of the earth at the moment the lower perforations are made by the gun. The packer, gun and the firing mechanism are left in the hole.



REEXAMINATION CERTIFICATE ISSUED UNDER 35 U.S.C. 307

THE PATENT IS HEREBY AMENDED AS INDICATED BELOW.

Matter enclosed in heavy brackets [ ] appeared in the patent, but has been deleted and is no longer a part of the patent; matter printed in italics indicates additions made to the patent.

AS A RESULT OF REEXAMINATION, IT HAS BEEN DETERMINED THAT:

The patentability of claims **1–6** and **11–24** is confirmed.

Claims **25** and **26** are cancelled.

Claim **7** is determined to be patentable as amended.

Claims **8–10**, dependent on an amended claim, are determined to be patentable.

7. In a well having a borehole which extends downhole through an upper and lower hydrocarbon containing zone, with each zone having at least one hydrocarbon containing formation, with the lower zone being isolated from the interior of the borehole by a well casing or the like, the method of completing the lower zone of the well after the upper zone has been completed comprising the steps of:

1. suspending a casing perforator means and a packer means from a tubing string;
2. setting the packer means downhole in the borehole at a location which positions the perforator means adjacent to at least one hydrocarbon containing formation of the lower hydrocarbon containing zone, while at the same time isolating the portion of the borehole underlying the packer means from the portion of the borehole located above the packer means;
3. forming an unobstructed flow path which extends from the borehole annulus underlying the packer means, into the tubing string, and uphole to the top of the borehole;
4. actuating the casing perforator means *while maintaining the unobstructed flow path* so as to perforate the casing and to communicate the hydrocarbon containing formation of the lower zone with the borehole annulus underlying the packer means to thereby enable production from the last named formation to flow through the perforations, into the lower borehole annulus underlying the packer means, into and up through the tubing string, and to the top of the borehole.

* * * * *