

Aug. 20, 1963

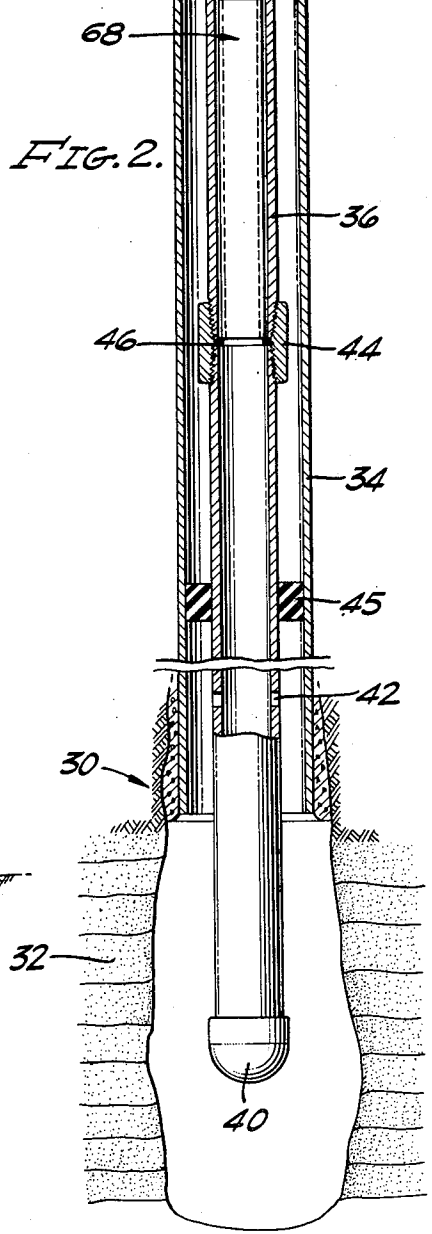
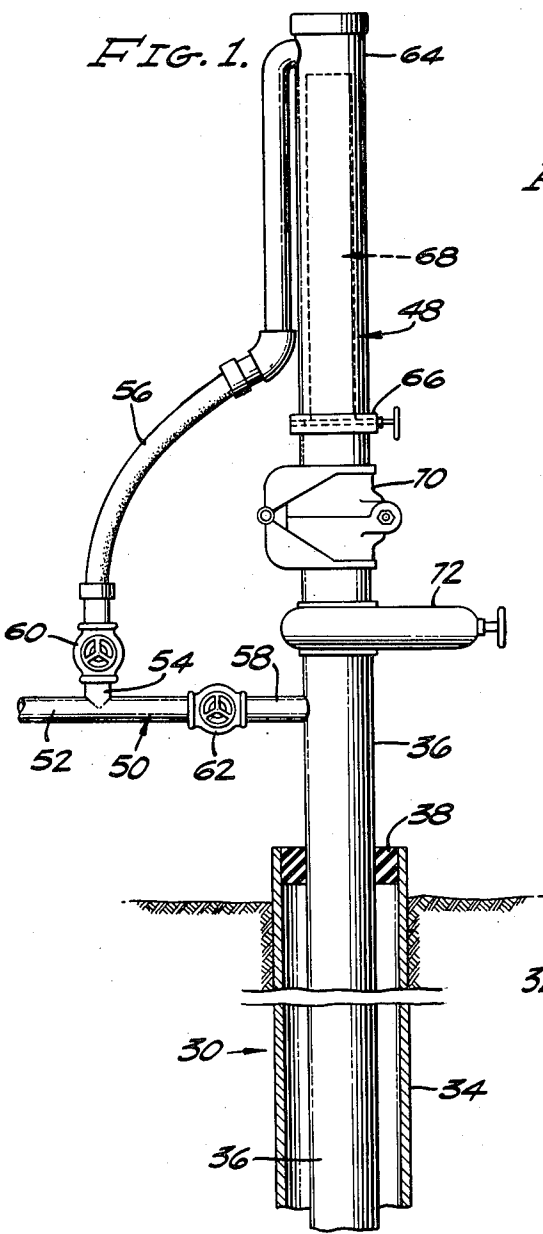
M. B. RIORDAN, JR

3,101,115

WELL TREATING METHOD AND APPARATUS

Filed Oct. 16, 1956

9 Sheets-Sheet 1



INVENTOR.
MATHEW B. RIORDAN, JR.
BY
Lyon & Lyon
ATTORNEYS

Aug. 20, 1963

M. B. RIORDAN, JR

3,101,115

WELL TREATING METHOD AND APPARATUS

Filed Oct. 16, 1956

9 Sheets-Sheet 2

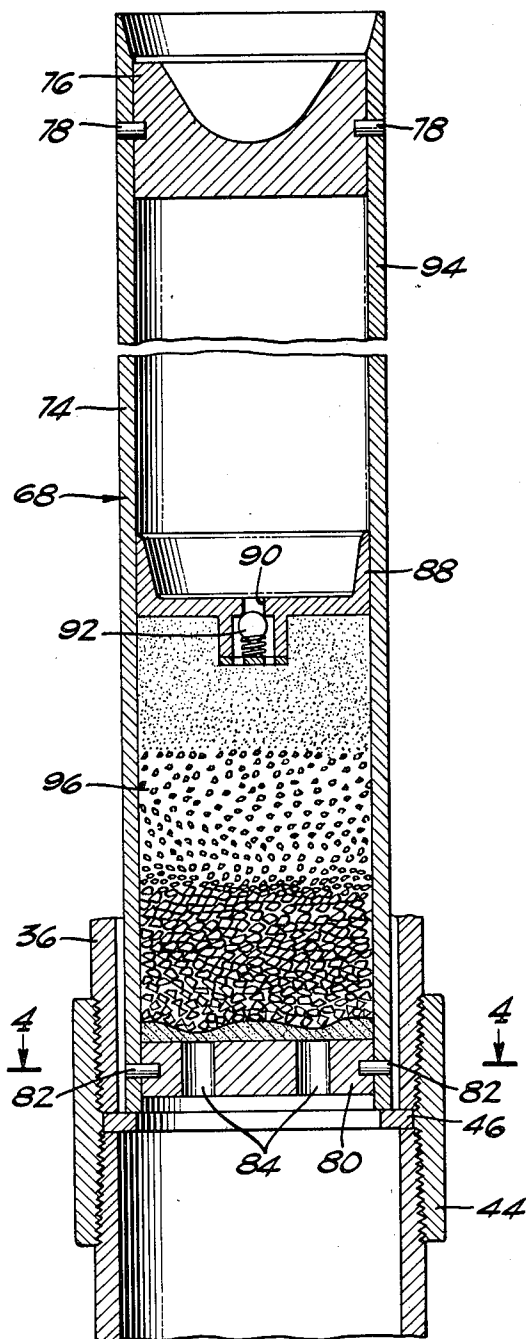


FIG. 3.

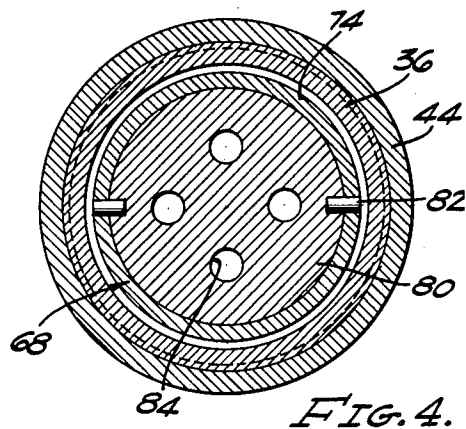


FIG. 4.

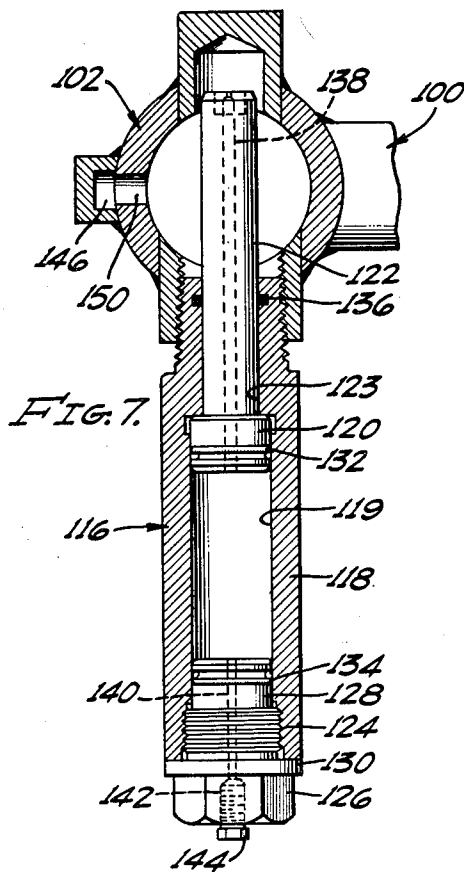


FIG. 7.

INVENTOR.
MATHEW B. RIORDAN, JR.
BY *Lyon & Lyon*
ATTORNEYS

Aug. 20, 1963

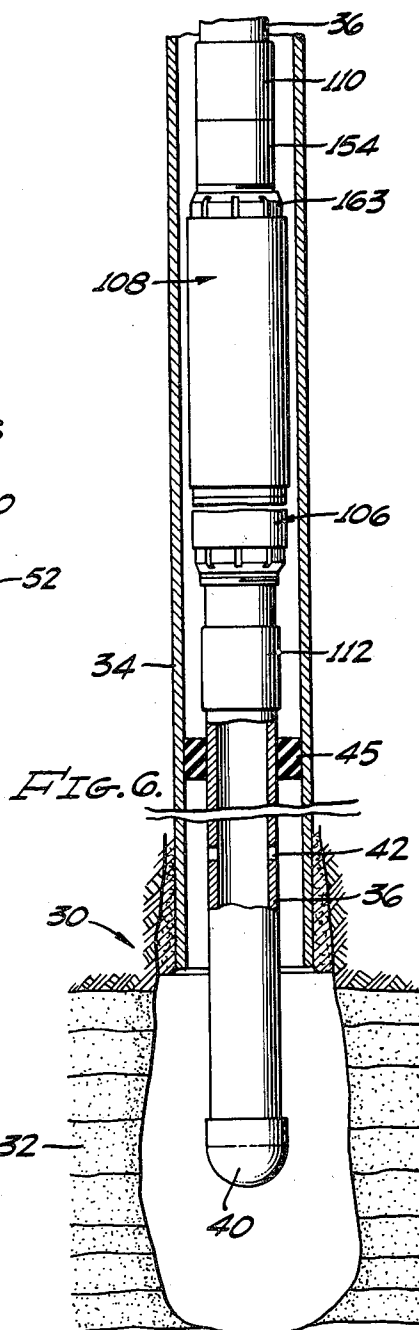
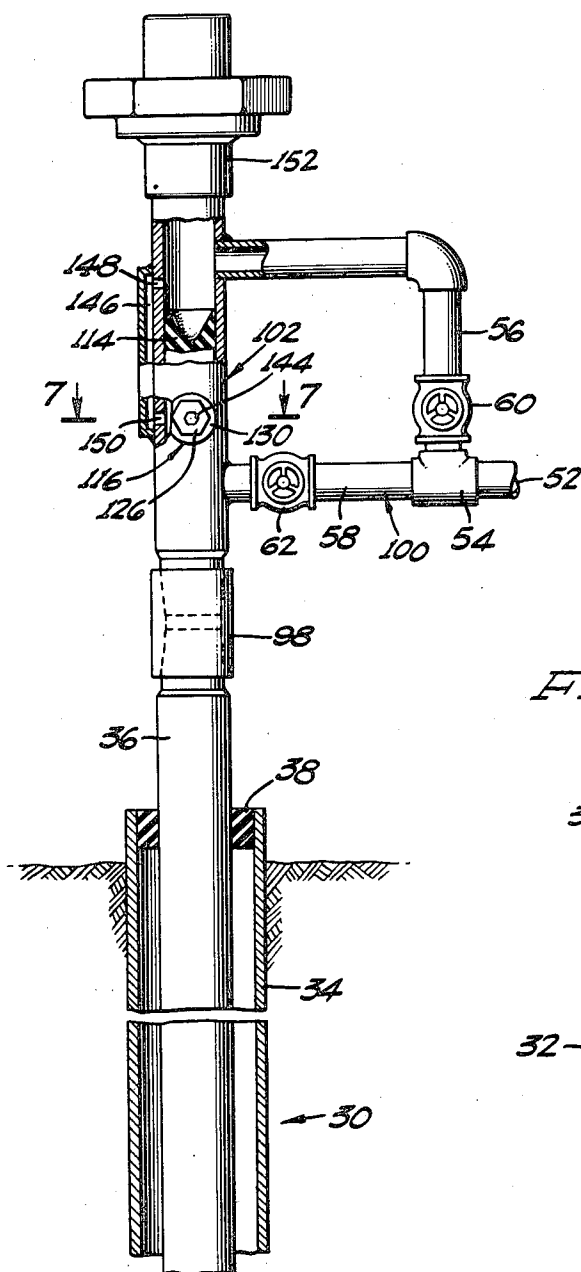
M. B. RIORDAN, JR

3,101,115

WELL TREATING METHOD AND APPARATUS

Filed Oct. 16, 1956

9 Sheets-Sheet 3



INVENTOR.

MATHEW B. RIORDAN, JR.

BY

Lyons Lyons
ATTORNEYS

Aug. 20, 1963

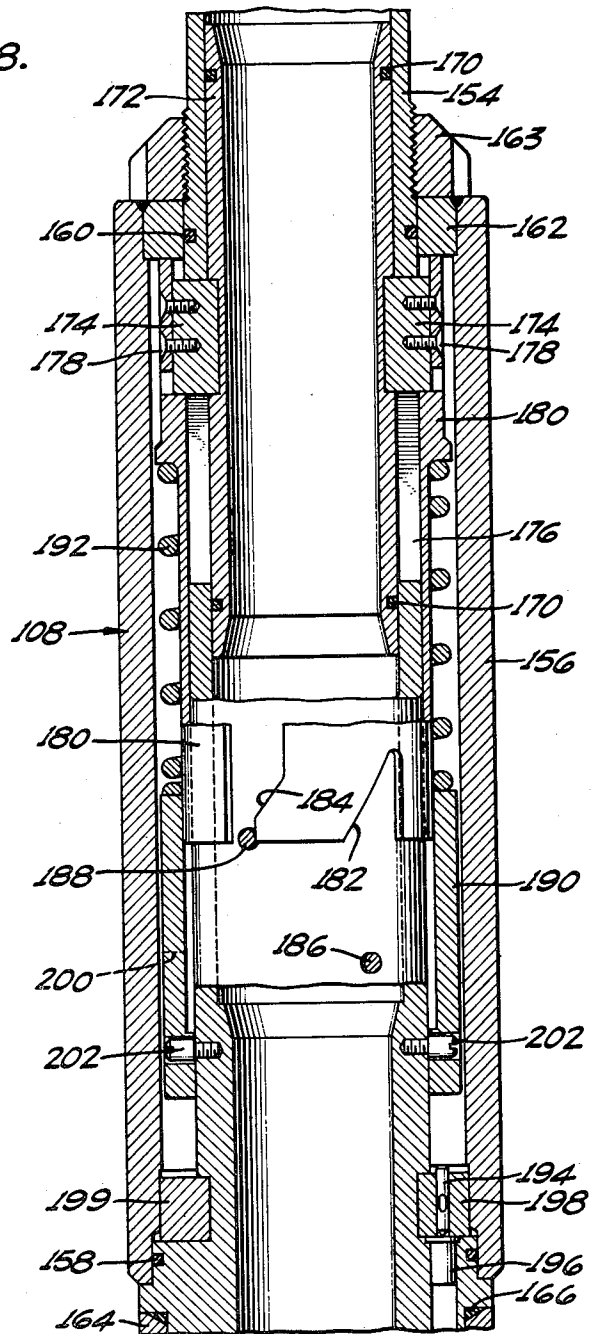
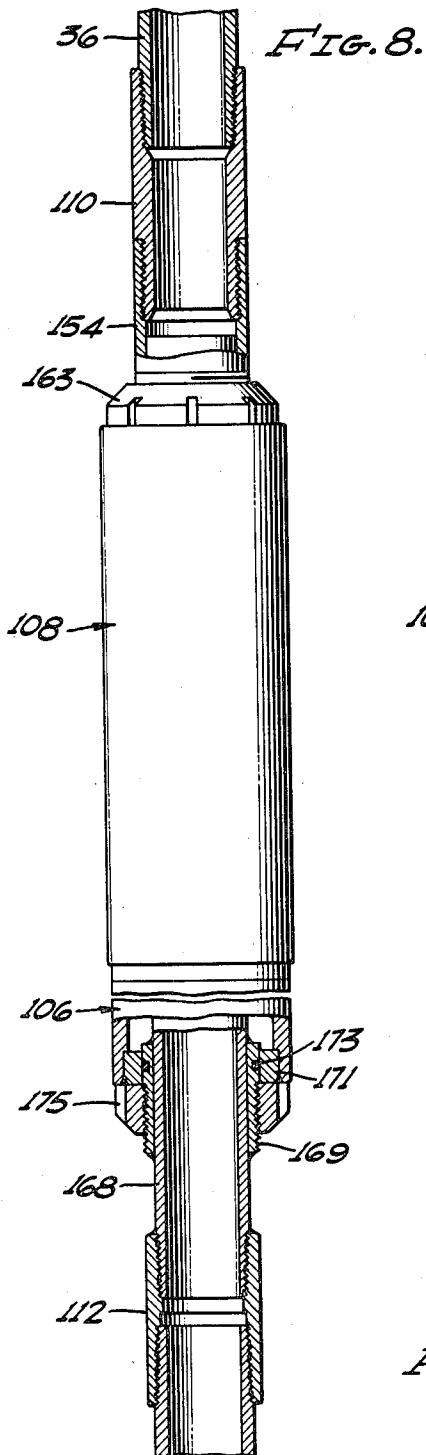
M. B. RIORDAN, JR

3,101,115

WELL TREATING METHOD AND APPARATUS

Filed Oct. 16, 1956

9 Sheets-Sheet 4



INVENTOR.
FIG. 9. MATHEW B. RIORDAN, JR.
BY *Lyon & Lyon*
ATTORNEYS

Aug. 20, 1963

M. B. RIORDAN, JR

3,101,115

WELL TREATING METHOD AND APPARATUS

Filed Oct. 16, 1956

9 Sheets-Sheet 5

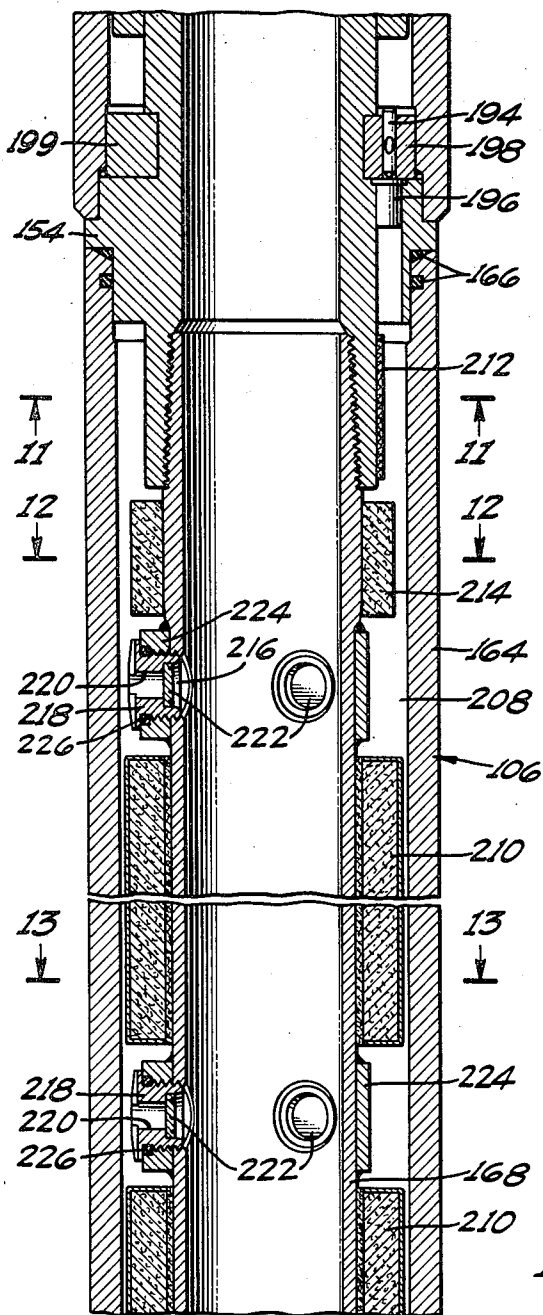


FIG. 10.

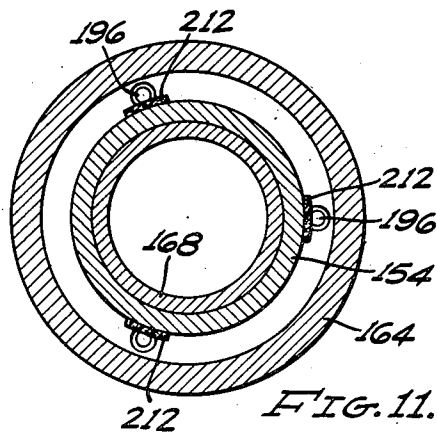


FIG. 11.

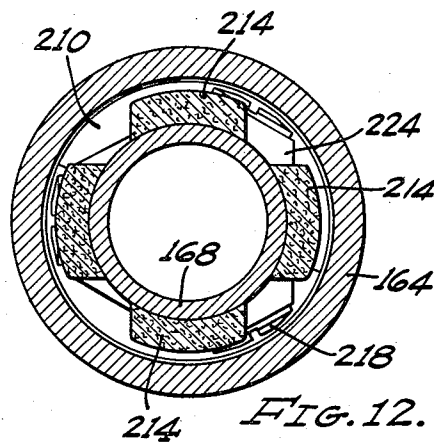


FIG. 12.

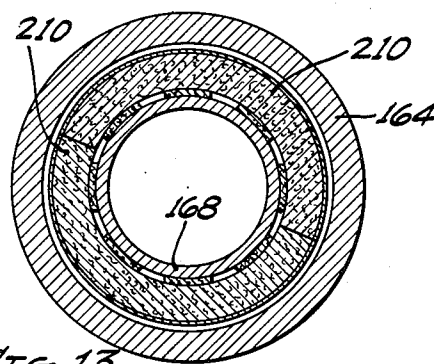


FIG. 13.

INVENTOR.
MATHEW B. RIORDAN, JR.

BY

Lyon & Lyon
ATTORNEYS

Aug. 20, 1963

M. B. RIORDAN, JR

3,101,115

WELL TREATING METHOD AND APPARATUS

Filed Oct. 16, 1956

9 Sheets-Sheet 6

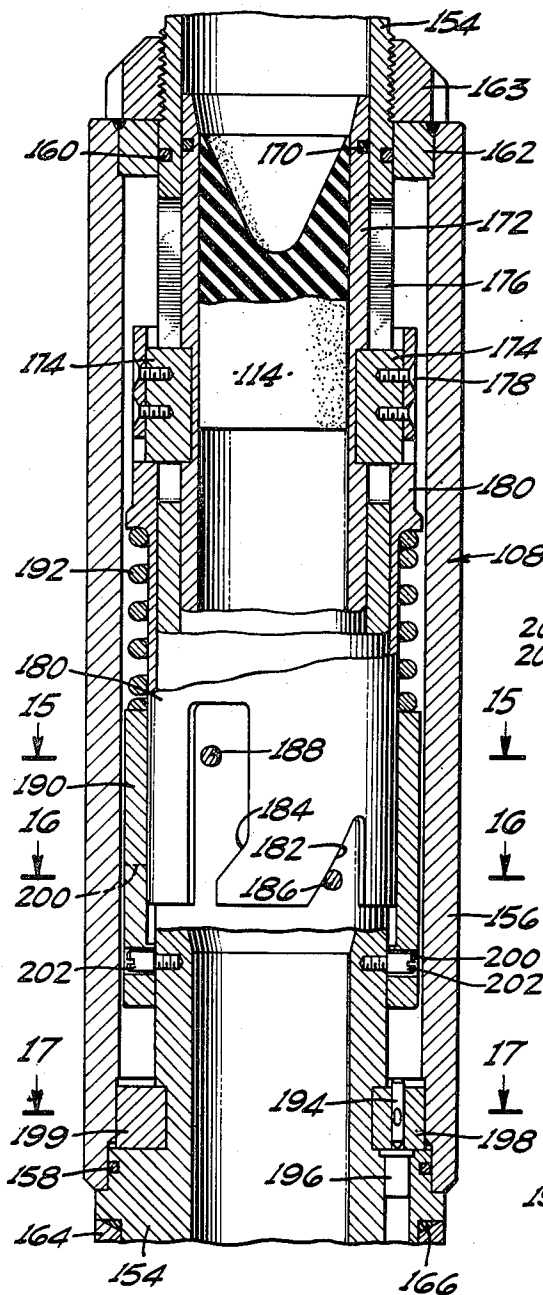


FIG. 14.

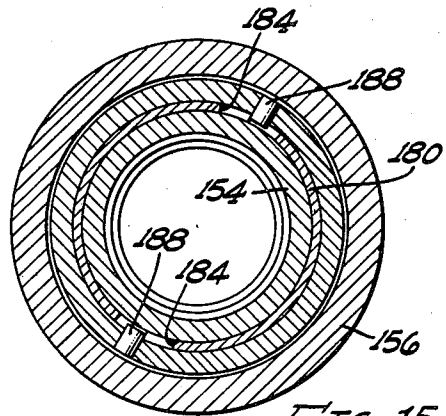


FIG. 15.

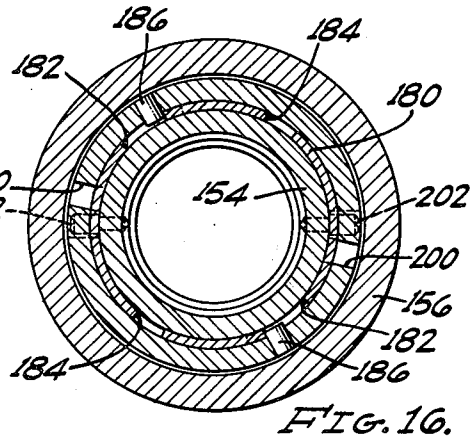


FIG. 16.

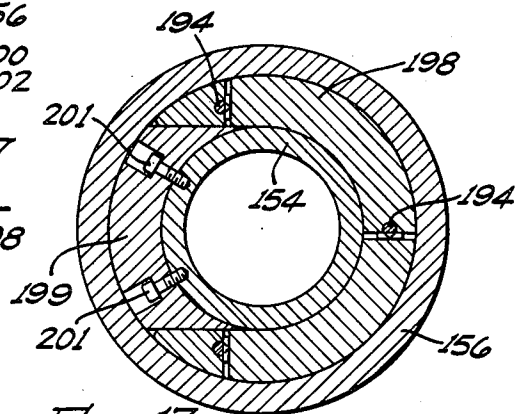


FIG. 17.

INVENTOR.
MATHEW B. RIORDAN, JR.
BY *Lyon & Lyon*
ATTORNEYS

Aug. 20, 1963

M. B. RIORDAN, JR

3,101,115

WELL TREATING METHOD AND APPARATUS

Filed Oct. 16, 1956

9 Sheets-Sheet 7

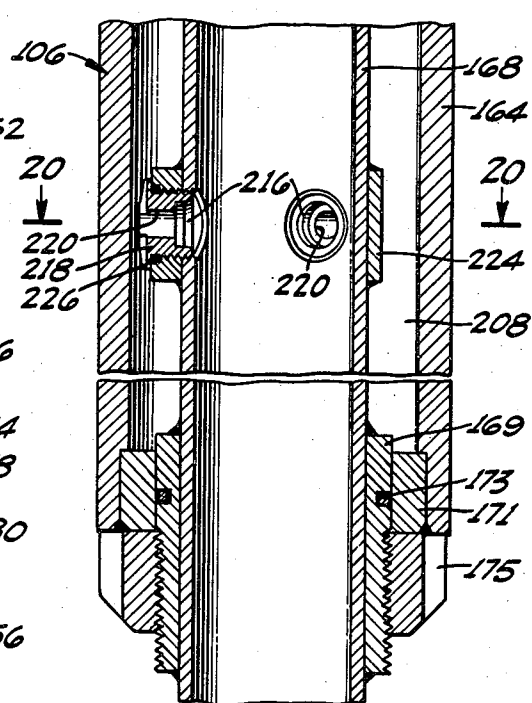
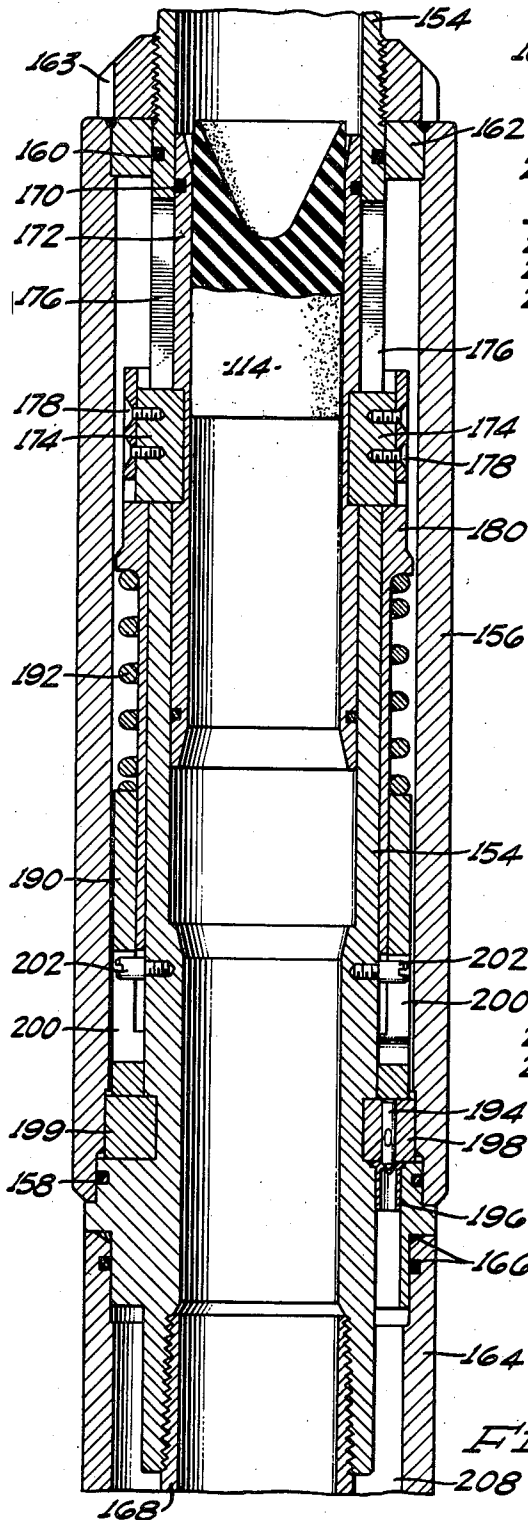


FIG. 19.

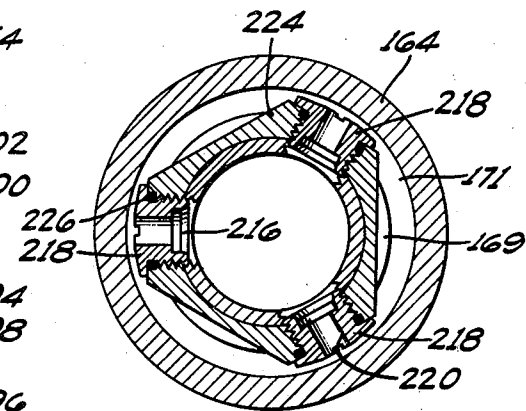


FIG. 20.

INVENTOR.
MATHEW B. RIORDAN, JR.
BY *Lyon & Lyon*
ATTORNEYS

Aug. 20, 1963

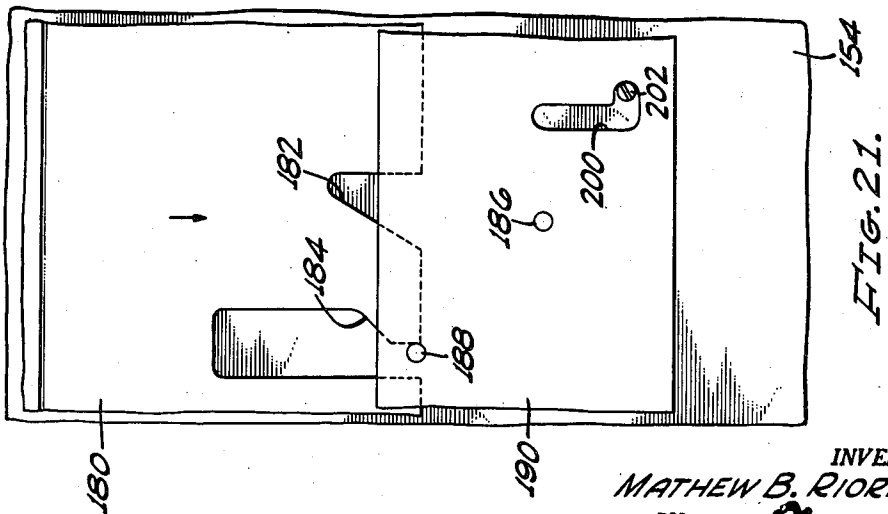
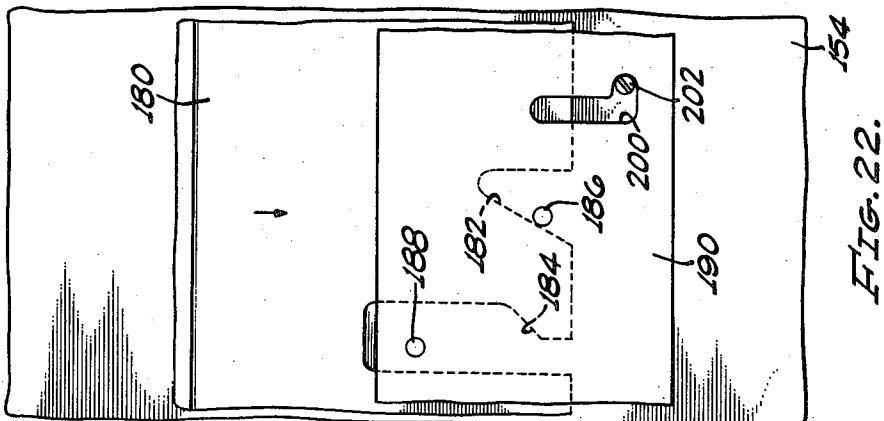
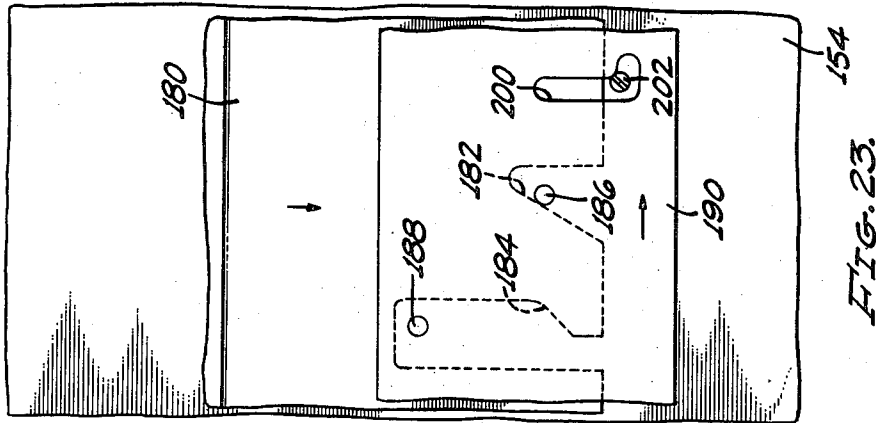
M. B. RIORDAN, JR

3,101,115

WELL TREATING METHOD AND APPARATUS

Filed Oct. 16, 1956

9 Sheets-Sheet 8



INVENTOR.
MATHEW B. RIORDAN, JR.
BY
Lyon & Lyon
ATTORNEYS

Aug. 20, 1963

M. B. RIORDAN, JR

3,101,115

WELL TREATING METHOD AND APPARATUS

Filed Oct. 16, 1956

9 Sheets-Sheet 9

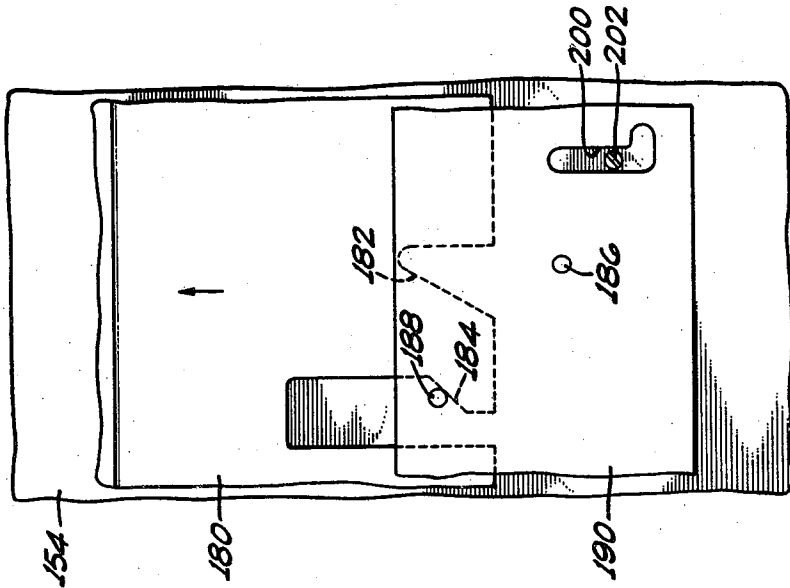


FIG. 25.

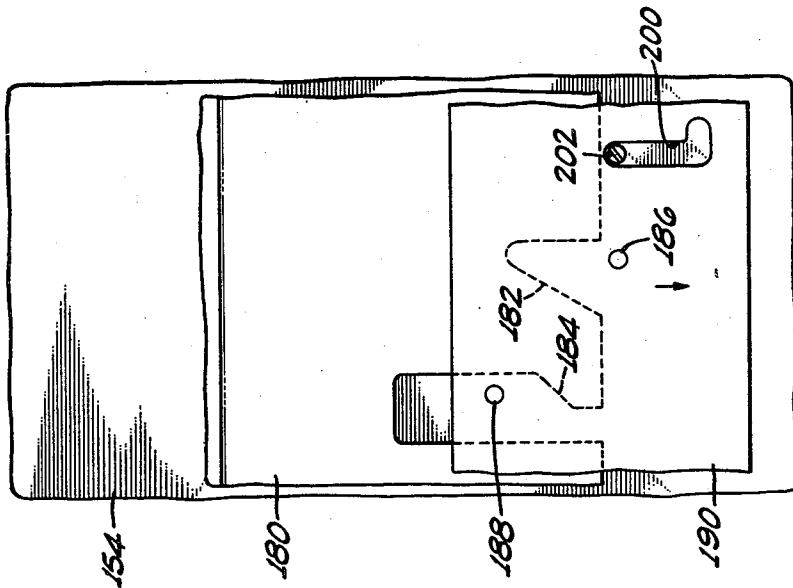


FIG. 24.

INVENTOR.
MATHEW B. RIORDAN, JR.
BY
Lyon & Lyon
ATTORNEYS

1

3,101,115

WELL TREATING METHOD AND APPARATUS
Mathew B. Riordan, Jr., La Habra, Calif., assignor to
BJ Service, Inc., Long Beach, Calif., a corporation of
Delaware

Filed Oct. 16, 1956, Ser. No. 616,223
21 Claims. (Cl. 166—42)

This invention relates to the treatment of wells and especially oil and gas wells.

In the art of drilling and completing wells, and particularly oil and gas wells, various occasions arise during which it is desirable that fluids be injected into the well under greater or lesser pressures. The pumping of such fluids may be desirable for the purpose of increasing the productivity of earth formations through or into which a well has been drilled, as by hydraulic fracturing. Similarly, it may be desirable for the purpose of cleaning perforations, liners and the like in the well, or indeed earth formation extending outwardly from the well. Again, fluid may be pumped into a well to remove water blocks or cones retarding production. It may be pumped into a well to consolidate sand, gravel and like materials adjacent the well bore. It may be pumped in for acidizing purposes. Additionally, in cementing operations cement slurry is pumped into wells for the purpose of anchoring casing, for the purpose of isolating various zones of the well and the like.

In these operations it is frequently necessary to obtain high fluid velocity rates, i.e., injection rates, or high pressures, the addition of considerable energy to the fluid system being consequently required. Thus, for example, in hydraulic well fracturing wherein oils or other fluids of varying characteristics are pumped into the well and from the well out into the formation for the purpose of fissuring or fracturing the formation to increase its permeability and hence its ability to produce oil, commercial experience has shown that oftentimes pressures extremely difficult to obtain become necessary. Similarly, commercial experience has established the value of high injection rates in this type of operation. In order to obtain the necessary pressures and/or the desired injection rates pumping equipment at the surface capable of delivering large amounts of energy to the fluid being pumped is required. Since the fracturing fluid must be pumped from wellhead to well bottom through casing or tubing, as the case might be, friction losses are involved which pose formidable problems, becoming ultimately insurmountable, even despite the willingness of the operator to provide virtually unlimited pumping capacity at the well site. The difficulty is present in greater or lesser degree in all the above mentioned operations, and such difficulty is two-fold, it being both an economic difficulty, and given the necessity of sufficiently high injection rates, a problem physically impossible of solution.

It is with this general problem that the instant invention is concerned, and the invention basically contemplates a means whereby added energy as a supplement to the energy available from the pumps may be imparted to the fluid injected into the well to increase fluid injection rates, pressure, or both. In this the invention contemplates a method whereby the aforesaid problem of frictional losses may be eliminated in all substantial respects so far as is concerned the added energy which supplements the energy afforded by the pumping units. This is accomplished through the use of a gas generating means placed adjacent the point of egress of the fluid from tubing or well casing, the energy supplied by the gas sharply increasing the fluid flow rate and/or pressure, and at the same time avoiding friction loss for the reason that the fluid in advance of the gas is not the fluid that must pass

2

from wellhead to egress point through substantial distances of pipe.

It is the basic object of the instant invention, therefore, to add energy to the fluid system involving a well into which fluid is being pumped, independently of the pumps.

It is a further object of this invention to add such energy in the vicinity of the point of fluid egress from casing, tubing or pipe to eliminate loss of such energy due to friction derived therefrom.

Similarly, it is a general object of this invention to provide a novel method and means whereby an energy source may be located in a well adjacent the site of an operation and activated to develop energy in the form of fluid horsepower to supplement the energy being delivered to the well through the surface pumping of the fluid.

Another object of the invention is to provide a combined method of displacing fluid in a well at high injection rates whereby a given injection rate is effected by one source, and during one or more selected time intervals an auxiliary or booster source is coupled to the moving body of fluid to effect for a relatively short time a high increment of added injection rate.

Yet another object of this invention is to provide a novel method and means for abruptly increasing the rate of injection of fluid within a well during the pumping of the fluid downwardly from the ground surface.

Yet a further object of the invention is to provide a novel method and means whereby gas under high pressure may be introduced into a moving body of fluid within a well to increase the injection rate and, hence, the pressure of said fluid.

And a still further object of the invention is to provide a novel method and means whereby the addition of such gas may be controlled by the rate of pumping from the ground surface.

Other objects and advantages of the invention will become apparent from the following detailed description, reference being had to the accompanying drawings, wherein:

FIGURE 1 is a fragmentary view and side elevation illustrating, in part schematically, one form of wellhead equipment for use in carrying out the method of this invention;

FIGURE 2 is a longitudinal sectional view of the lower portion of the well shown in FIGURE 1 and includes bottom hole equipment used in carrying out the aforesaid method;

FIGURE 3 is an enlarged longitudinal sectional view of the gas generator shown generally in FIGURE 2;

FIGURE 4 is a transverse sectional view taken on line 4—4 of FIGURE 3;

FIGURE 5 is a view similar to that of FIGURE 1 showing another form of apparatus for use in carrying out the method of the invention;

FIGURE 6 is a view similar to FIGURE 2 showing the lower portion of the well of FIGURE 5 including therein the apparatus;

FIGURE 7 is a transverse sectional view taken on line 7—7 of FIGURE 5;

FIGURE 8 is a view in side elevation, with parts broken away, of the aforesaid modified apparatus;

FIGURE 9 is an enlarged longitudinal sectional view of the upper portion of the apparatus of FIGURE 5, showing the parts in initial position with respect to operation;

FIGURE 10 is a downward continuation of FIGURE 9;

FIGURES 11, 12 and 13 are transverse sectional views taken respectively on lines 11—11, 12—12, 13—13 of FIGURE 10;

FIGURE 14 is a view similar to FIGURE 9 but showing the parts in an intermediate stage of operation;

FIGURES 15, 16 and 17 are transverse sectional views

3

taken respectively on lines 15, 16 and 17 of FIGURE 14;

FIGURE 18 is a view similar to FIGURES 9 and 14 but showing the parts in a subsequent position;

FIGURE 19 is a downward continuation of FIGURE 18 and shows the lower end of the apparatus;

FIGURE 20 is a transverse sectional view taken on line 20—20 of FIGURE 19; and

FIGURES 21 to 25 are schematic views illustrating successive relative positions of the cam mechanism showing in FIGURES 9 and 14.

As stated hereinabove, the instant invention generally comprises a method and apparatus for conducting the method whereby a gas generating propellant is positioned adjacent the egress point for the well fluid in the well bore and the injection rate and/or pressure of said fluid increased through the generation of gas by said propellant whereby energy is added to that afforded by the surface pumping units and used to impart to the fluid in the system the increased injection rates and pressures.

Referring now to the drawings, and particularly to FIGURES 1 and 2, whereby a particular utilization of the method and a particular embodiment of the apparatus is shown, a well generally designated 30 is shown drilled into a producing or potentially producing formation 32, and well casing 34 extending to a level adjacent the upper boundary of the formation 32 has been cemented in place. A string of well tubing 36 is suspended in the well by conventional wellhead equipment indicated schematically at 38 with the lower end of the tubing extending below the lower end of the casing 34, the tubing having a bull plug or other closure member 40 at its lower end, the said lower end of the tubing being slotted as at 42 and being connected to the tubing string by a stop collar 44 provided with a restricting seat 46 of lesser inner diameter than the inner diameter of the said tubing. Packing off of the tubing 36 against the casing 34 is indicated at 45. Conventionally, hold down slips, not shown, may be used in association with the packer.

The tubing string at the surface is provided with a well-head lubricator generally designated 48, to which is connected a valve manifold, generally designated 50. The valve manifold comprises the conduit 52 which is split by the T 54 into two conduits 56 and 58, the latter being provided respectively with the valves 60 and 62 and connecting respectively with the lubricator chamber 64 and tubing 36. The lubricator chamber 64 is itself provided with a trap or insertable pin assembly 66 which releasably supports the propellant canister 68 to be hereinafter described, and the chamber is connected through a hinged union 70 to the tubing 36 whereby the said chamber may be pivoted away from the tubing to permit insertion of the canister 68. Shown on the tubing 36 is the master gate valve 72.

Referring now to FIGURES 3 and 4 wherein the canister 68 is shown in detail, such canister comprises a housing or shell 74 closed by an upper plug 76 affixed to the shell by shear pins 78 and closed by lower plug 80 affixed to the shell by the shear pins 82, the plug 80 having ports 84 and supporting shear disk 86.

The interior of the canister is divided into two compartments by the slidable sealing cup 88, which sealing cup is provided with a port 90 against which seats a ball check valve 92 permitting fluid flow only downwardly through the canister. The upper compartment of the canister is filled with a fluid 94 and the lower compartment with a material 96 adapted to react with or catalyze the fluid 94 to provide generation of gas. Various gas generating reactions, catalytic or otherwise, are well-known. In the illustrated embodiment of the invention the fluid 94 may comprise a mono-propellant such as hydrogen peroxide, H_2O_2 . As is likewise well-known, hydrogen peroxide decomposes by reaction or catalysis in the presence of various organic or inorganic material to produce quantities of gas. In the illustrated embodiment the material 96 may comprise an inorganic catalyst which

4

promotes the decomposition of the hydrogen peroxide. Available catalysts for this phenomenon are widely known, such as lead, iron, copper, silver, cobalt, carbon and manganese. The catalyst may have varying physical forms as, for example, iron screen alone or screen suitably coated with silver, copper, manganese, cobalt or the like. The catalyst may likewise be in the form of impregnated porous stones or indeed mere particles of the aforesaid substances. It has been found desirable that the catalyst particles be graded from fine particles in the upper portions of the compartment to coarser particles in the lower portions to avoid the blowing out of unused catalyst through the ports 84. As is apparent, it is the purpose of the propellant canister to permit the fluid 94 upon the exercise of suitable pressure, to flow through the check valve 92, and through the catalytic or reacting material 96, whereupon gas is generated which bursts the shear disk 86 and flows through the ports 84.

In operation of this form of the invention which is described in connection with a hydraulic well fracturing operation, the lubricator chamber 64 is pivoted by the union 70 and the trap 66 opened to permit the insertion of the canister 68, whereupon the trap is closed and the lubricator 64 pivoted back to its vertically closed position. With the master gate valve 72 and valve 60 closed and the valve 62 open the fracturing operation is proceeded with in conventional manner, fluid such as jelled hydrocarbon, crude oil or other liquid being pumped by the surface pumps through the conduit 52 down the tubing 36, out of the slots 42 and into the formation 32. It is the purpose of the fracturing operation, of course, to fissure the formation 32 and in the usual case to introduce sand carried by the fluid being pumped into the formation itself into the fissures to retain those fissures propped open so that productivity of the formation may be enhanced.

Since the nature of various formations will generally vary widely, different conditions will be encountered. Frequently, extremely high pressures will be necessary in order to accomplish the fracturing of the formation. On the other hand, relatively permeable formations may be encountered in which case effective fracturing pressures are difficult of attainment, due simply to fluid loss into the formation. After fracturing it is desirable to introduce as much sand as is possible into the fissures in the formation, and sufficient flow rates must be continuously maintained so that the sand may be retained suspended in the fluid lest it be dropped within the well bore to require a shutting down of operations and a bailing out of the well. It will be apparent, therefore, that continuous high flow rates are important and indeed essential to successful fracturing and that higher flow rates produce optimum results. As aforesaid, however, continuous flow rates have depended upon the energy delivered to the system by the surface pumps, and the long lengths of tubing 36, usually many thousands of feet, render inevitable friction losses. As injection rates increase, regardless of the willingness of the operator to incur high expense in additional pumping equipment, these friction losses become insurmountable. Indeed, the point is rapidly reached where as injection rate at the surface is gradually increased friction losses rise until neither bottom hole pressures nor bottom hole flow rates may be further increased lest the tubing adjacent the surface of the well be burst.

Accordingly, the instant invention is utilized and energy is added to the system in the vicinity of the actual treating operation to increase flow rate and/or pressure while neither interrupting the continuous delivery of energy to the system by the surface pumps nor losing any substantial amount of the added energy to friction.

Without stopping the pumps the valves 60 and 72 are opened. The trap 66 is then opened, permitting the descent of the canister 68. It is noted that an hydraulic pin such as that shown in FIGURE 7 of the drawings and

subsequently described may be used in place of the trap 66. The valve 62 may be closed to assist descent of the canister into the tubing if necessary. The canister 68 then progresses down the tubing due to the continuous pumping of the fluid through the manifold 50 until it reaches the position shown in FIGURE 2, it then being checked by the collar seat 46. Fluid pressure immediately becomes effective on the upper plug 76 within the canister 68 to shear the pins 78. The plug drives the hydrogen peroxide 94 through the ball check valve 92 and it passes through the catalyst 96, the said catalyst causing its progressive decomposition into gas. The gas thus produced bursts the shear disk 86 and rushes through the ports 84 and out the ports 42 in the tubing 36, driving, of course, the fluid below the canister and the fluid which has previously been pumped against and into the formation 32 before it at tremendously increased injection rates, thereby incrementing the energy in the system.

Due to the movement of the upper plug 76 the hydrogen peroxide will, of course, gradually all be forced through the valve 92 and the catalyst 96 and hence will be decomposed. When the plug 76 reaches the sealing cup 88 both continue to move downwardly and the force imposed upon the shear pins 82 by these members, by the catalyst 96 and by the lower plug 80 causes shearing of the said pins. Thereafter the upper plug 76, the sealing cup 88 and its associated ball check valve 92, the catalyst 96, the shear disk 86 and the lower plug 80 all pass through the tubing 36, coming to rest below the ports 42 within the lower extremity of said tubing. The valve 62 may then be opened, the valves 60 and 72 closed and the fracturing operation continued in conventional manner. As will have been observed, the immediately described valving arrangement could have been utilized as soon as the canister passed the main gate valve during its descent into the tubing.

It is notable that in the above operation decomposition of the fluid propellant and consequent gas formation takes place over a relatively long period of time, preferably on the order of about ten seconds, it being necessary to avoid sharp pressure peaks such as would be occasioned by the use of detonating explosives and the like. On the other hand, the inherent nature of the invention enables relatively simple control of gas production and consequently of the time interval during which the additional energy is imparted to the system. In addition to the obvious control available through the use of different fluids and catalysts, the rate of passage of the fluid 94 through the catalyst 96 is a function of the pumping rate at the surface and, thus, relatively rapid or relatively slow gas generation may be readily achieved.

After the incrementing of the energy to the system through utilization of the instant invention, the conventional well treatment, such as in this case fracturing, may proceed. It may, however, be desirable that additional increments of energy be added. Another canister 68 is inserted into the lubricator 64 and pumped down to seat upon the housing or shell 74 of the previously used canister, which housing or shell, of course, has remained seated upon the collar seat 46. When the second canister reaches its seated position the continuing fluid pressure afforded by the surface pumps causes gas generation and the delivery of a second increment of energy to the system, after which the plugs, valving and the like within the second canister are deposited at the bottom of the tubing, leaving the shell of the second canister seated on the shell of the first. As will be apparent, the nature of the apparatus permits a plurality of canisters to be used in similar manner.

Referring now to FIGURES 5 through 25, inclusive, of the drawings, there is shown alternate apparatus for carrying out the method of the instant invention, the apparatus itself being claimed in copending application Serial No. 120,872, filed June 19, 1961, as a continuation of application Serial No. 616,333, filed concurrently here-

with in the names of Lyle B. Scott and Mathew B. Riordan, Jr. In FIGURES 5 and 6 as in FIGURES 1 and 2 the well 30 is drilled into the formation 32 and the well casing 34 cemented in place, the string of tubing 36 being suspended within the well by conventional wellhead equipment 38 and having the bull plug or other closure member 40 at its lower end. Again, the lower end of the tubing is slotted as at 42 and the tubing is packed as at 45. In association with the packer may be conventional hold-down slips not shown.

At the surface connected to tubing string 36 by a collar 98 is a valve manifold generally designated 100. The valve manifold comprises the conduit 52 which is split by the T 54 into two conduits 56 and 58, the latter being provided respectively with the valves 60 and 62 and connecting respectively with the manifold body 102 at its upper and lower portions.

As distinguished from the apparatus formerly shown, no gas generating canister is insertable within the manifold 102. On the contrary, a gas generator 106 with associated firing head 108 is made up in the string of tubing adjacent its lower end, such gas generating tool being connected at its upper extremity to the tubing 36 through the adapter 110 and at its lower extremity to the said tubing by a collar 112. The gas generator is fired by the dropping of the plug 114, which is shown in FIGURE 5, within the manifold 102, such plug being retained within the manifold by a hydraulic pin 116.

The hydraulic pin 116, which is shown in FIGURE 7, functions to provide an improved means for dropping the plug 114 without releasing system pressure, i.e., without requiring the stopping of the surface pumps. It constitutes a cylindrical pin body 118 threaded into the manifold body 102, the pin body being bored at 119 to receive a piston 120 slidable in said bore from which piston extends the pin 122 slidable in the diminished bore 123 of the said pin body. The outer extremity of the pin body is counter bored as at 124 and threadably receives the nut 126 from which extends into the bore 119 the plug portion 128. The nut 126 shoulders on the head 130.

O-rings 132 and 134 are provided to seal respectively at the piston 120 and plug 124 and O-ring 136 provides a seal between the pin body and the pin 122. A passage 138 is provided through the pin 122 and piston 120 and a similar passage 140 is provided through the plug 128, the said passage 140 being extended through the nut 126 by the counterbore 142. A screw valve 144 threads into the counterbore 142 seating against the passage 140.

Since the cross-sectional area of the piston 120 exceeds that of the pin 122, it is readily seen that the foregoing assembly provides a differential area piston. So long as the screw valve 144 remains closed, fluid pressure within the manifold 100 retains the pin 122 in its closed position across the manifold to retain the plug 114 within the manifold. Release of the screw valve 144 permits pressure to bleed away from the outer side of the piston 120 whereby fluid pressure forces the pin 122 from its closed position permitting the plug 114 to drop from the manifold 102. Subsequent closing of the screw 144 causes a fluid pressure buildup on the outer face of the piston 120 which returns the pin to its closed position. For the purpose of by-passing the plug 114 a passage 146 having ports 148 and 150 is provided in the manifold 102. A union or cap 152 is threaded to the upper manifold body 102.

Referring now to the firing head 108, as previously stated it is connected to the tubing string 36 by an adapter 110, the said adapter being threaded into the firing head body 154 which itself is encompassed by a firing head case 156 sealed at its lower extremity to said body by an O-ring 158 and at its upper extremity by an O-ring 160, there being a ring 162 interposed between body and case. A nut 163 threads on the firing head body 154 to retain the case in place. A gas generator casing 164 is sealed with respect to the firing head body 154 by O-rings 166, an orifice tube 168 within said gas generator case being

7

threaded into the lower extremity of the firing head body. As shown in FIGURE 19, a bushing 169 is welded to the orifice tube and a ring 171 welded to the gas generator casing 164 and interposed between bushing and casing. O-ring 173 provides a seal, and the nut 175 threaded on to the bushing holds the casing in place.

As will be hereinafter described, the gas generator 106 carries a slow burning propellant, which upon being fired, generates the gas within the system, thus imparting the additional energy thereto. Firing is accomplished by the firing head 108. Slidable within said firing head in the firing head body 154 and sealed with respect thereto by the O-rings 170 is an inner sleeve 172, the inner sleeve 172 carrying drive lugs 174. The drive lugs 174 are adapted to slide within the slots 176 of the firing head body 154 and themselves are affixed as by the screws 178 to a firing cam 180 which is rotatable on the firing head body and includes the cam surfaces 182 and 184. These cam surfaces are adapted to coact with the pin followers 186 and 188, which pin followers are integral with and project inwardly from an annular hammer 190, a spring 192 being interposed between the annular hammer and the firing cam to cause the hammer to strike the firing pins 194 to fire the percussion cap 196 in manner to be hereinafter described. The firing pins 194 are slidably supported by a breech block 198 carried by the firing head body 154, a filler plug 199 being also supported by the firing head body and affixed thereto by the screws 201. L-slots 200 coacting with pins 202 projecting from the firing head body 154 control descent of the hammer 190.

Firing of the cap 196, as previously stated, is accomplished by the hammer 190 which descends through action of the spring 192, FIGURE 9 of the drawings showing the firing head mechanism prior to firing, FIGURE 14 showing the mechanism about to fire and FIGURE 18 showing it, in part, after firing. FIGURES 21 through 25 diagrammatically show the action between the firing cam 180 and its cam surfaces 182 and 184 and the hammer 190 and its pin followers 186 and 188. When the hydraulic pin 116 is caused to permit the plug 114 to drop down through the tubing it comes to rest within the inner sleeve 172 as shown in FIGURE 14, the said plug being of resilient composition such as rubber and of such dimensions as to be wedgeable within the said inner sleeve in tight frictional fit. Fluid pressure afforded by the surface pumps then imparts through the plug 114 a downward force to the inner sleeve, which through the drive lugs 174 urges the firing cam 180 downwardly against the spring 192. This drops the firing cam 180 from its position shown in FIGURES 9 and 21 to the position shown in FIGURES 14 and 22 and pin follower 186 is caused to ride along the cam surface 182, thereby rotating the hammer 190. Rotation of the hammer 190 moves the pins 202 from the closed portions of the L slots 200 towards the open portions thereof as shown in FIGURE 23 until the hammer is free to descend sharply under the urging of the spring 192. This is shown in FIGURE 24 and the result whereby the said hammer drives the pins 194 into the caps 196 to fire same is shown in FIGURE 18. Firing of the caps 196 of course sets off the propellant within the gas generator 106 in manner to be hereinafter described.

During the aforesaid operation of the tool, the plug 114, after the sleeve 172 has reached the end of its travel is caused by fluid pressure to be expelled from the sleeve and to be deposited in the lower extremity of the tubing 36. Recocking of the tool at the surface is shown in FIGURE 25, movement back of the firing cam 180 with respect to the hammer 190 and against the spring 192 causing the pin 188 to ride on the cam surface 184, thereby rotating back the said hammer until the pins 202 are disposed within the closed portions of the L slots 200. The tool is then cocked for firing and in the position shown in FIGURE 9.

Referring now to the gas generator 106, it has already

8

been noted that the gas generator casing 164 is sealed with respect to the firing head body 154 by O-rings 166 and with respect to the orifice tube 168 by the O-ring 173 to provide an annulus 208, in which annulus is placed the gas generating propellant.

The gas generating propellant used is a slow burning propellant requiring on the order of 10 seconds to burn completely and is shown in split ring form as the propellant 210. While the gas generator is shown foreshortened in the drawings, it may consist of considerable length such as, for example, 15 feet in comparison with a length of about 2 feet for the firing head. Thus, a number of split rings of propellant 210 may be utilized. The propellant itself may be one diverse so-called slow burning propellants such as rubberized ammonium nitrate and the like. Such a solid propellant may be obtained, for example, from Grand Central Rocket Company in Mentone, California, under their designations "CBS-128K" or "CBS-128H." It may comprise ordinary railroad fuses material, such as sawdust impregnated with sodium or ammonium nitrate, or it may comprise one of a variety of rocket fuels. Suitable propellants are described in "Chemistry of Powder and Explosives," 1943, by T. L. Davis, John Wiley and Son. As is well-known, these solid propellants may be adjusted in composition to burn at varying rates, but as stated, about 10 seconds is preferable when used with the instant invention.

In order to insure firing of the propellant, as a result of firing of the caps 196, additional propellant 212 and 214 is used to form a firing train to the main bodies of propellant 210 and although varying arrangements within the skill of those trained in the art may be availed of, in the instant embodiment of the propellant 212 is shown in strip form glued to the firing head body 154 terminus adjacent the caps 196. The propellant 214 is shown interposed between the aforesaid strips and the main body of propellant in strip form but glued to the orifice tube 168 and somewhat thicker, providing therefor a propellant train of gradually decreasing surface area relative to propellant volume.

Prior to the firing of the herein described tool the orifice tube 168 is subjected to the pressure of the fluid being pumped into the formation through the tubing 36. The annulus 208 is therefore sealed from such fluid, but to provide means whereby the gas generated by the propellant 210 may enter the orifice tube and hence the tubing, sealing ports 216 are provided in the orifice tube. These tubing ports 216 are sealed by the plugs 218 and provided with the bores 220 sealed by the sealing disks 222, the said plugs being threaded into the rings 224 welded to the orifice tubes. O rings 226 provide a seal between the rings 224 and plugs 218. Since the sealing disks seat upon shoulders facing inwardly, the aforesaid plug arrangement provides an effective means to prevent fluid egress from the ports but permits upon burning of the propellant 210 the issuance of gas into the orifice tube, the sealing disks 222 being, of course, blown from the plugs 218 by the gas.

The method of the instant invention is conducted using the instant apparatus just as in the case of the previously described apparatus and, as with the previously described apparatus, this apparatus is used to increment the energy added to the fluid being pumped into the well by the surface pumps. The tool, however, is run into the well as part of the tubing string. Before the job starts the plug 114 is placed within the upper portion of the manifold body 102 by removing the cap 152 and held suspended therein by the hydraulic pin 116 which is in its closed, i.e., extended, position. With the valve 60 closed and the valve 62 opened, the pumping operation is proceeded with in the usual manner utilizing the surface pumps, the passage 146 affording opportunity for the fluid pressures upon the plug 114 to balance. When it is desired to increment the energy in the system the screw valve 144 is opened, permitting opening of the hydraulic pin 116, the valve 60

being opened and the valve 62 closed. Since the surface pumps continue to run this causes the plug 114 to be pumped down through the tubing until it reaches the inner sleeve 172 through which it is pumped. Friction between the plug and the sleeve 172, however, causes the said sleeve to move downwardly with respect to the firing head body 154, causing, as previously described, the firing pins 194 to be driven into the caps 196, whereupon flame from the said caps ignites the propellant train, gas is generated within the annulus 208 and the said gas bursts through the ports 216 passing through the tubing and driving the fluid before it into the formation.

As distinguished from the first described apparatus, it is not possible to reuse the instant apparatus in situ to add a plurality of increments of energy to the fluid being pumped. On the contrary, the tubing must be pulled from the well and new propellant providing about the orifice tube. This is readily accomplished by the unthreading of the nut 175 and the sliding off the gas generator casing 164. Recocking of the firing head 108 is made possible by the unthreading of the nut 163 and the sliding off of the firing head case 156.

To provide an example of the carrying out of the method on an actual well, General Petroleum Tonner No. 23 in the Brea Olida field was fractured and the instant invention utilized in such fracturing. Casing had been set in the well and terminated by a slotted liner hung from 2730 ft. to 3139 ft., the liner being perforated from 2795 ft. to 3139 ft. Tubing was run down into the well terminated by a perforated tail pipe acting both as a plug catcher and to carry a subsurface pressure recorder. Above the perforated tail pipe was provided a packer and slip assembly for packing off the annulus between tubing and casing and anchoring the tubing. The packer assembly was positioned at 2710 ft. Immediately above the packer was the apparatus shown in FIGURES 5 through 25 of the drawings and above that apparatus the tubing string. The position of the apparatus was therefore approximately 85 ft. from the perforations. Pressure gauges were provided for the tubing at the surface and at the pump truck.

The tubing and annulus were first filled with lease crude oil after which fracturing operations commenced. 20 barrels of the crude oil were pumped down the tubing at a rate of 6 barrels per minute, the bottom hole pressure, the tubing pressure and the pump truck pressure all gradually rising until during the pumping of said 20 barrels of oil breakdown pressure was achieved. Such pressure was recorded as 2500 p.s.i. at the bottom of the well, approximately 2000 p.s.i. in the tubing at the surface of the well and approximately 2500 p.s.i. at the truck.

After the displacing of the aforesaid 20 barrels of oil, but without stopping the pump truck and continuing the pumping rate of 6 barrels per minute the plug 114 was permitted to descend in the tubing. When the plug reached the firing head 108 the apparatus fired and the propellant in the gas generator 106 generated gas to provide the desired additional energy to the system. During and after the travel of the plug 114 to the firing head and the operation of the tool, additional oil was pumped into the tubing all at a rate of 6 barrels per minute. Thus pumping at the 6 barrel per minute rate was continuous from the commencement of the fracturing job until after the operation of the tool. Pressure gauges showed that when the tool fired, pressure at the bottom of the well rose to 3100 p.s.i., at the surface in the tubing to 2950 p.s.i. and at the pump truck to 3400 p.s.i. The tubing was then pulled and the tool prepared for further use. No damage appeared to be occasioned to either the tool, the wellhead equipment or the subsurface equipment.

The solid propellant used in the tool in the aforesaid conducting of the method of the invention had a burning rate of .098 inch per second. Subsequently, and on the following day, the same well was subjected to the same treatment, using, however, a solid propellant having a burning rate of .135 inch per second. The same proce-

dures was followed but firing of the tool and consequent gas generation caused higher pressures because of the faster burning rate of the propellant. Bottom hole pressure was indicated to be 4150 p.s.i. Pressure in the tubing at the surface was 3300 p.s.i., and pump truck pressure 3900 p.s.i. Again when the tubing was pulled no damage was evident as concerns either surface or subsurface equipment.

The foregoing establishes the effectiveness of the instant method in affording a very substantial increment of energy available for addition to the energy provided by the pumping trucks in an hydraulic pumping operation. On the first day the addition of this energy was evidenced by a bottom hole pressure rise of 600 p.s.i., by a tubing pressure rise of approximately 1000 p.s.i. and by a pump truck pressure rise of about 900 p.s.i. On the second day the pressure differentials were respectively about 1600 p.s.i., 900 p.s.i. and 1500 p.s.i. These pressure rises caused by the operation of the tool required no shutting down of surface pump operations. On the contrary, the surface pumps maintained a fluid flow rate of 6 barrels per minute continuously during the operations.

While the instant invention has been described particularly in connection with fracturing operations, its utility is manifest wherever it is desired to increase flow rates and/or pressures when pumping fluids into wells. As previously indicated, this operation is involved in many types of well treatments. Consequently, the invention is deemed to include that which is defined by the full scope of the following claims.

I claim:

1. The method of introducing fluid under pressure into earth formation into or through which a well has been drilled comprising: pumping fluid through the well into said formation from the earth surface; disposing a material below said surface and adjacent said formation capable of gas generation within the well; and inducing the generation of gas by said material responsive to and during said surface pumping to increase the pressure acting on the fluid and force the same into said earth formation.

2. The method of introducing fluid under pressure into earth formation into or through which a well has been drilled comprising: pumping fluid through the well into said formation from the earth surface; disposing a second fluid below said surface and adjacent said formation capable of gas generation within the well; inducing by the pumping of fluid the generation of gas by said second fluid during said surface pumping, and implementing the rate of injection of fluid into said earth formation with said gas.

3. The method of introducing fluid under pressure into earth formation into or through which a well has been drilled comprising: pumping fluid through the well into said formation from the earth surface; while pumping introducing within said well a second fluid and a material within the well adjacent said second fluid capable upon contact therewith to cause said second fluid to generate gas within said well; continuing such surface pumping to cause contact between said second fluid and said material responsive to and during said pumping to generate gas and implementing the rate of injection of fluid into said earth formation with said gas.

4. Fluid injection apparatus for a well comprising: surface pumping means for pumping fluid into said well; a compartmented container adapted to be lowered in said well in said fluid; a gas generating fluid within a first compartment of said container; a material in a second compartment of said container capable upon contact with said gas generating fluid of causing said gas generating fluid to generate gas within said well; means for arresting movement of said container downwardly in said well and means responsive to operation of said surface pumping means for establishing contact between said

11

fluid and said material when such downward movement is arrested.

5. In fluid injection apparatus for a well to which is connected surface pumping equipment for pumping fluid into said well the combination comprising: a compartmented container adapted to be lowered in said well in said fluid; a gas generating fluid within a first compartment of said container; a material in a second compartment of said container capable upon contact with said gas generating fluid of causing said fluid to generate gas within said well; means for arresting movement of said container downwardly in said well and means responsive to operation of said surface pumping equipment for establishing contact between said fluid and said material when such downward movement is arrested.

6. Fluid injection apparatus for a well comprising: surface pumping means for pumping fluid into said well; a container adapted to be lowered in said well in said fluid; means for arresting movement of said container downwardly in said well; a gas generating fluid within an upper compartment of said container; a material within a lower compartment of said container capable upon contact with said gas generating fluid of causing said fluid to generate gas; a valve between said compartments responsive to operation of said surface pumping means when said downward movement of said container is arrested to permit passage of said gas generating fluid from said upper compartment into said lower compartment; and gas egress ports in said lower compartment for permitting flow of gas from said lower compartment into said well.

7. In fluid injection apparatus for a well to which is connected surface pumping equipment for pumping fluid into said well the combination comprising: a container adapted to be lowered in said well in said fluid; means for arresting movement of said container downwardly in said well; a gas generating fluid within an upper compartment of said container; a material within a lower compartment of said container capable upon contact with said gas generating fluid of causing said fluid to generate gas; a valve between said compartments responsive to operation of said surface pumping equipment when said downward movement of said container is arrested to permit passage of said gas generating fluid from said upper compartment into said lower compartment; and gas egress ports in said lower compartment for permitting flow of said gas from said lower compartment into said well.

8. Fluid injection apparatus for a well comprising: surface pumping means for pumping fluid into said well; a lubricator at the surface of said well, said lubricator including a chamber; a container insertable in said chamber for lowering in said well in said fluid; said lubricator including means for releasably holding said container in said chamber and operable to release said container for movement downwardly in said well; a gas generating fluid within an upper compartment of said container; a material within a lower compartment of said container capable upon contact with said gas generating fluid of causing said fluid to generate gas; means responsive to operation of said surface pumping means when downward movement of said container is arrested to permit passage of said gas generating fluid from said upper compartment into said lower compartment; and gas egress ports in said lower compartment for permitting flow of gas from said lower compartment into said well.

9. Apparatus for introducing fluid into earth formation into or through which a well has been drilled comprising: surface pumping means for pumping fluid into said well; a lubricator at the surface of said well, said lubricator including a chamber; a container insertable in said chamber for lowering in said well in said fluid responsive to operation of said surface pumping means; said lubricator including means for releasably holding said container in said chamber and operable to release said container for movement downwardly in said well; a con-

12

tainer seating element within said well adjacent said earth formation; a gas generating fluid within an upper compartment of said container; a material within a lower compartment of said container capable upon contact with said gas generating fluid of causing said fluid to generate gas; a valve between said compartments responsive to operation of said surface pumping means upon seating of said container on said seating element to permit passage of said gas generating fluid from said upper compartment into said lower compartment; and gas egress ports in said lower compartment for permitting a flow of gas from said lower compartment into said well.

10. The method of injecting fluid under pressure into earth formation into which or through which a well has been drilled, comprising: pumping fluid into the well from the earth surface, disposing a gas generating material in said well and generating from said material responsive to and during said pumping a volume of gas at a pressure greater than incipient pressure of the fluid in the well below said surface, and thereby increasing the pressure acting on the fluid and forcing the fluid into said earth formation.

11. The method of introducing fluid under pressure into earth formation into which or through which a well has been drilled, comprising: pumping fluid through said well into said earth formation thereby imposing continuing hydraulic pumping pressure upon said fluid at the surface of the well to displace the fluid into the formation; incrementing said continuing hydraulic pumping pressure upon said fluid by generating a plurality of successive volumes of gas in the fluid being pumped within the well adjacent said formation during a series of selected time intervals responsive to the pumping of fluid through said well into the earth formation while continuing said pumping and maintaining said hydraulic pump pressure.

12. The method of injecting fluid under pressure into earth formation into which or through which a well has been drilled, comprising: pumping fluid into the well from the earth surface; while pumping introducing a second fluid below said surface capable of gas generation within the well; inducing responsive to fluid pressure caused by the pumping of said fluid generation of gas by said second fluid during said surface pumping to increase the pressure acting on said fluid, and implementing the rate of injection of fluid into said earth formation with said gas.

13. The method of injecting fluid under pressure into earth formation into which or through which a well has been drilled comprising: pumping fluid into the well from the earth surface; while pumping introducing within said well a second fluid and a material within the well adjacent said second fluid capable upon contact therewith to cause said second fluid to generate gas within said well; continuing such surface pumping to cause contact between said second fluid and said material responsive to and during said pumping to generate gas and increase the pressure acting on said fluid thereby implementing the rate of injection of fluid into said earth formation with said gas.

14. The method of injecting fluid under pressure into earth formation into which or through which a well has been drilled comprising: pumping fluid into the well from the earth surface; while pumping introducing hydrogen peroxide and a material capable upon contact with said hydrogen peroxide to cause decomposition of said hydrogen peroxide to generate gas within said well; continuing such surface pumping to cause contact between said hydrogen peroxide and said material responsive to and during said pumping to generate gas and increase the pressure acting on said fluid thereby implementing the rate of injection of fluid into said earth formation.

15. The method of introducing fluid under pressure into earth formation into or through which a well has been drilled comprising: pumping fluid through the well into said formation from the earth surface; while pumping introducing within said well hydrogen peroxide and a

13

material within the well adjacent said hydrogen peroxide capable upon contact therewith to cause decomposition of said hydrogen peroxide to generate gas within said well; continuing such surface pumping to cause contact between said hydrogen peroxide and said material responsive to and during said pumping to generate gas and increase the pressure acting on said fluid thereby implementing the rate of injection of fluid into said earth formation with said gas.

16. The method of injecting fluid under pressure into earth formation into which or through which a well has been drilled comprising: pumping fluid into the well from the earth surface; while pumping introducing within said well a second fluid and a material capable upon intermixing therewith to cause said second fluid to generate gas within said well at a rate in proportion to the rate of said intermixing; continuing such surface pumping at a selected rate to cause controlled intermixing between said second fluid and said material responsive to and during said pumping to generate gas and increase the pressure acting on said fluid thereby implementing the rate of injection of fluid into said earth formation with said gas.

17. The method of introducing fluid under pressure into earth formation into or through which a well has been drilled comprising: pumping fluid through the well into said formation from the earth surface; introducing within said well a second fluid and a material adjacent said second fluid capable upon intermixing therewith to cause said second fluid to generate gas within said well at a rate in proportion to the rate of said intermixing; continuing such surface pumping at a selected rate to cause controlled intermixing between said second fluid and said material responsive to and during said pumping to generate gas and implement the rate of injection of fluid into said earth formation with said gas.

18. Apparatus for introducing fluid into earth formation into or through which a well has been drilled comprising: surface pumping means for pumping fluid into said well; a container adapted to be lowered in said well and positioned adjacent said earth formation; gas generating material within said container, and fluid pressure operated means responsive to the pumping of fluid into said well by said surface pumping means for causing said material to generate a volume of gas implementing fluid pressure in said well supplied by said surface pumping means.

19. Apparatus for introducing fluid into earth formation into or through which a well has been drilled comprising: surface pumping means for pumping fluid into

14

said well; a container; means for supporting said container in said well adjacent said earth formation; material within said container adapted to generate gas within said well; and fluid pressure operated means for causing said material to generate said gas responsive to and during operation of said surface pumping means, said gas implementing fluid pressure in said well supplied by said surface pumping means.

20. Apparatus for introducing fluid into earth formation into or through which a well has been drilled comprising: surface pumping means for pumping fluid into said well; a container adapted to be lowered in said well in said fluid responsive to operation of said surface pumping means; a container seating element within said well adjacent said earth formation; gas generating material within said container; and fluid pressure operated means for causing said material to generate said gas responsive to and during operation of said surface pumping means upon said container seating on said seating element, said gas implementing fluid pressure in said well supplied by said surface pumping means.

21. Apparatus for introducing fluid into earth formation into or through which a well has been drilled comprising: surface pumping means for pumping fluid into said well; a lubricator at the surface of said well; said lubricator including a chamber; a container insertable in said chamber for lowering in said well in said fluid; said lubricator including means for releasably holding said container in said chamber and operable to release said container for movement downwardly in said well; a container seating element within said well adjacent said earth formation; gas generating material within said container, and fluid pressure operated means for causing the generation of gas by said material upon seating of said container on said seating element.

References Cited in the file of this patent

UNITED STATES PATENTS

1,806,499	Ranney et al.	May 19, 1931
2,676,662	Ritzmann	Apr. 27, 1954
2,712,355	Hoff	July 5, 1955
2,732,016	MacLeod	Jan. 24, 1956
2,756,826	Ebaugh	July 31, 1956
2,766,828	Rachford	Oct. 16, 1956
2,776,014	Lee et al.	Jan. 1, 1957
2,781,099	Chesnut	Feb. 12, 1957
2,811,209	Elkins	Oct. 29, 1957