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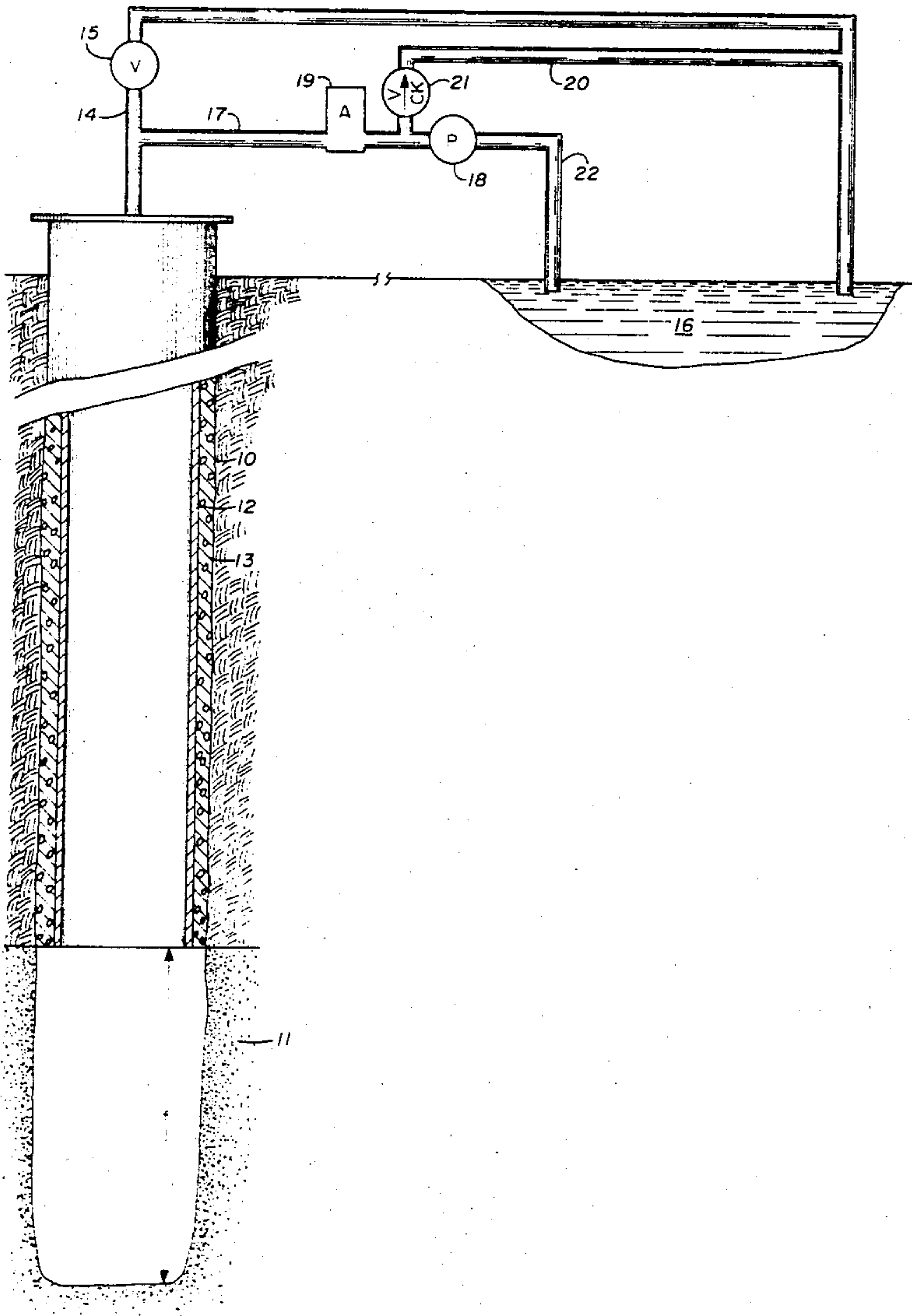
[54] **PRESSURE PULSE HYDRAULIC FRACTURING
FOR SUBSURFACE FORMATIONS**
13 Claims, 4 Drawing Figs.

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166/177
[51] Int. Cl..... E21b 43/26
[50] Field of Search..... 166/249,
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ABSTRACT: Subsurface formations are fractured by a process wherein a first path of flow of a fracturing fluid is established from a pump through a flow control-hammer valve, and a second path of flow is established to the formation to be fractured from a point between the pump and the valve, the pressure of the fluid against the formation from the second path of flow being controlled at a predetermined level, preferably slightly less than the formation fracture pressure, by controlling the fluid flow through the valve in the first path of flow. Next, the flow through the valve is instantaneously terminated to cause a pressure pulse to be transmitted through the second path of flow and against the formation and to cause fracturing thereof. In one embodiment, a rarefaction pulse is transmitted down the second path of flow a spaced distance behind the pressure pulse to cause a decay of the pressure pulse after it has reflected from the formation and before it radiates up the well casing and damages the system.



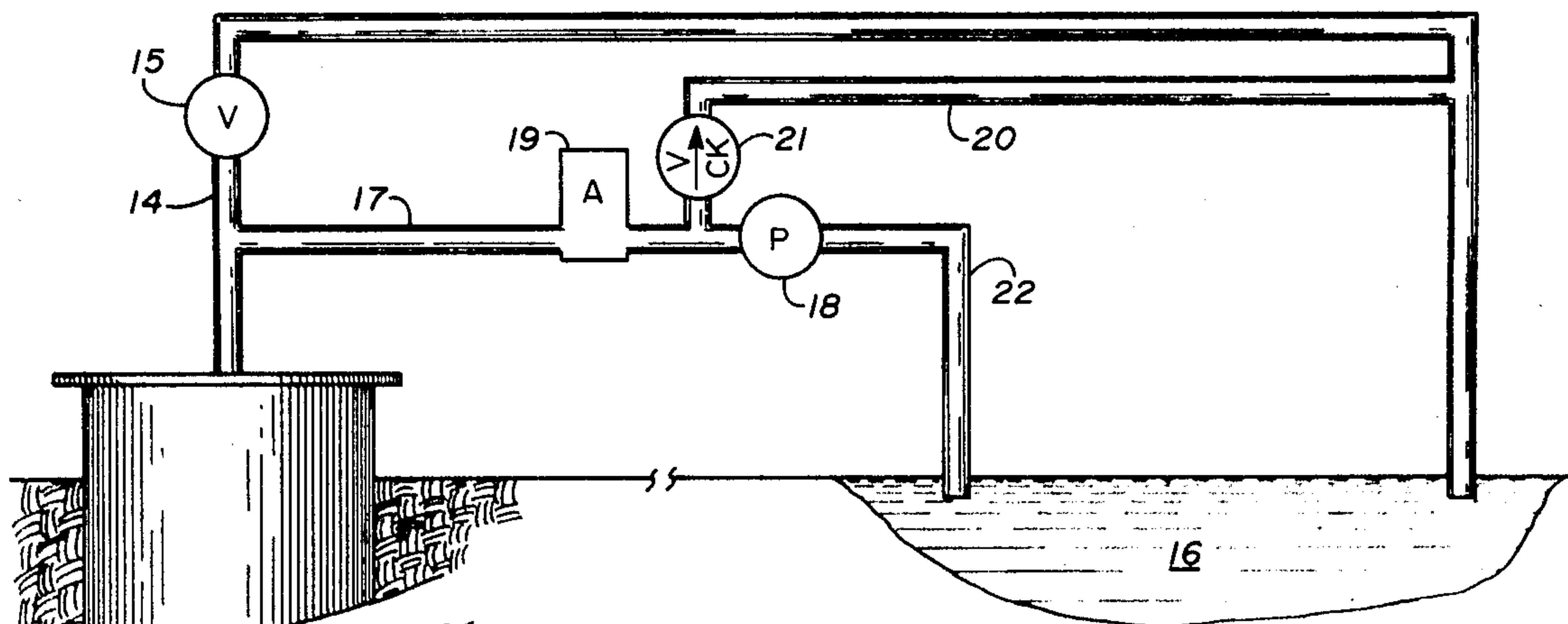


FIG. 1

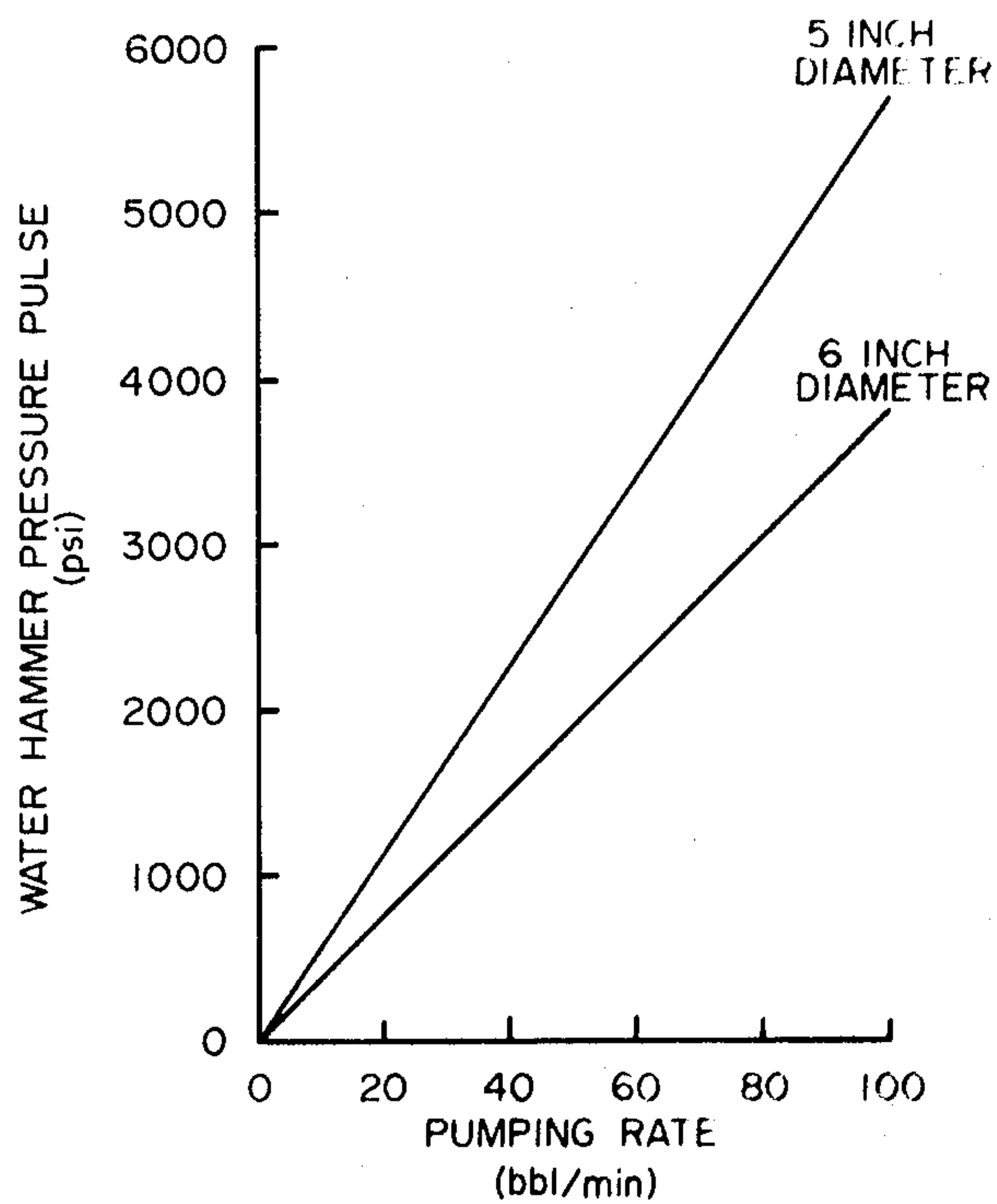


FIG. 4

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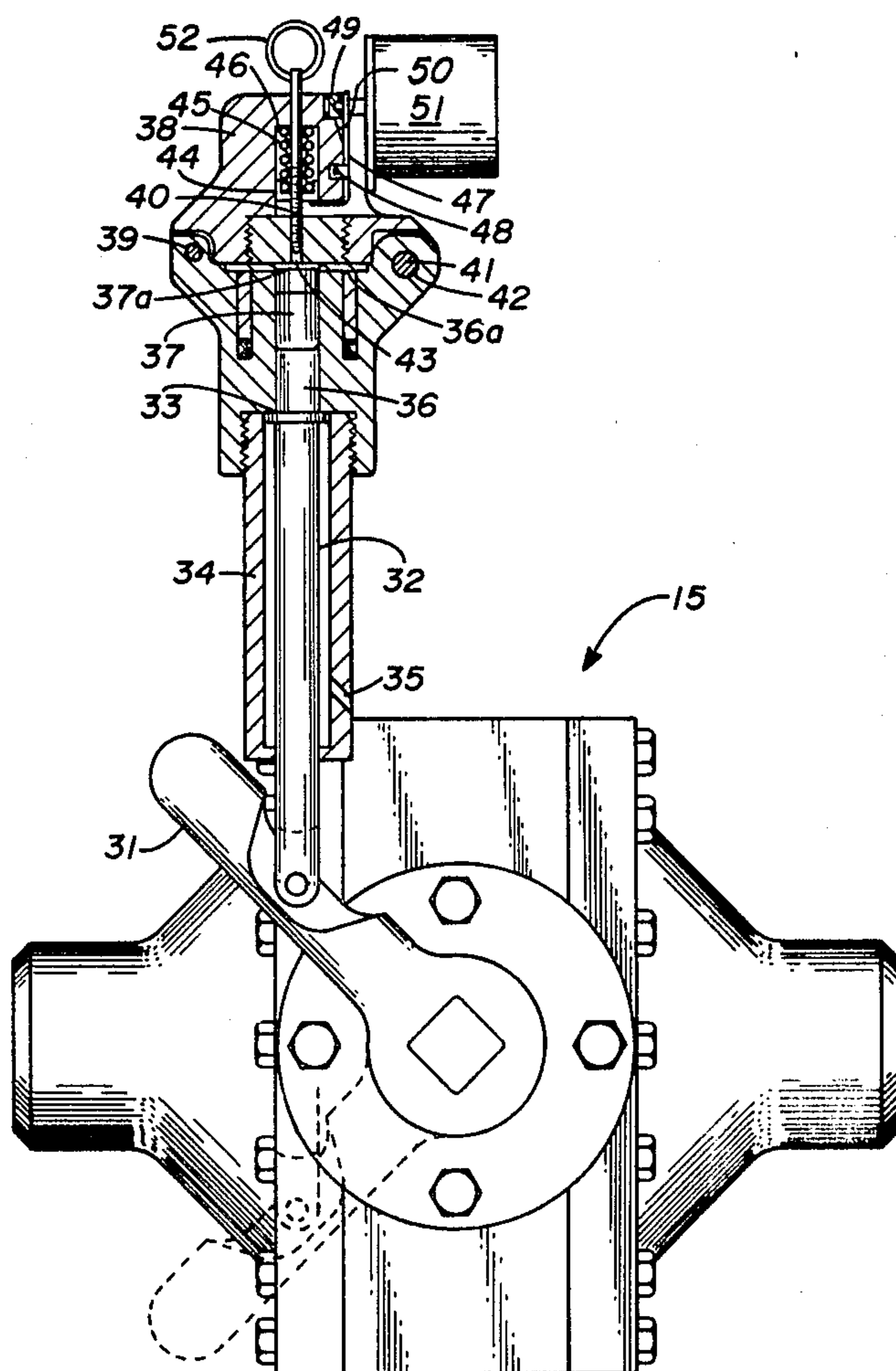


FIG. 2

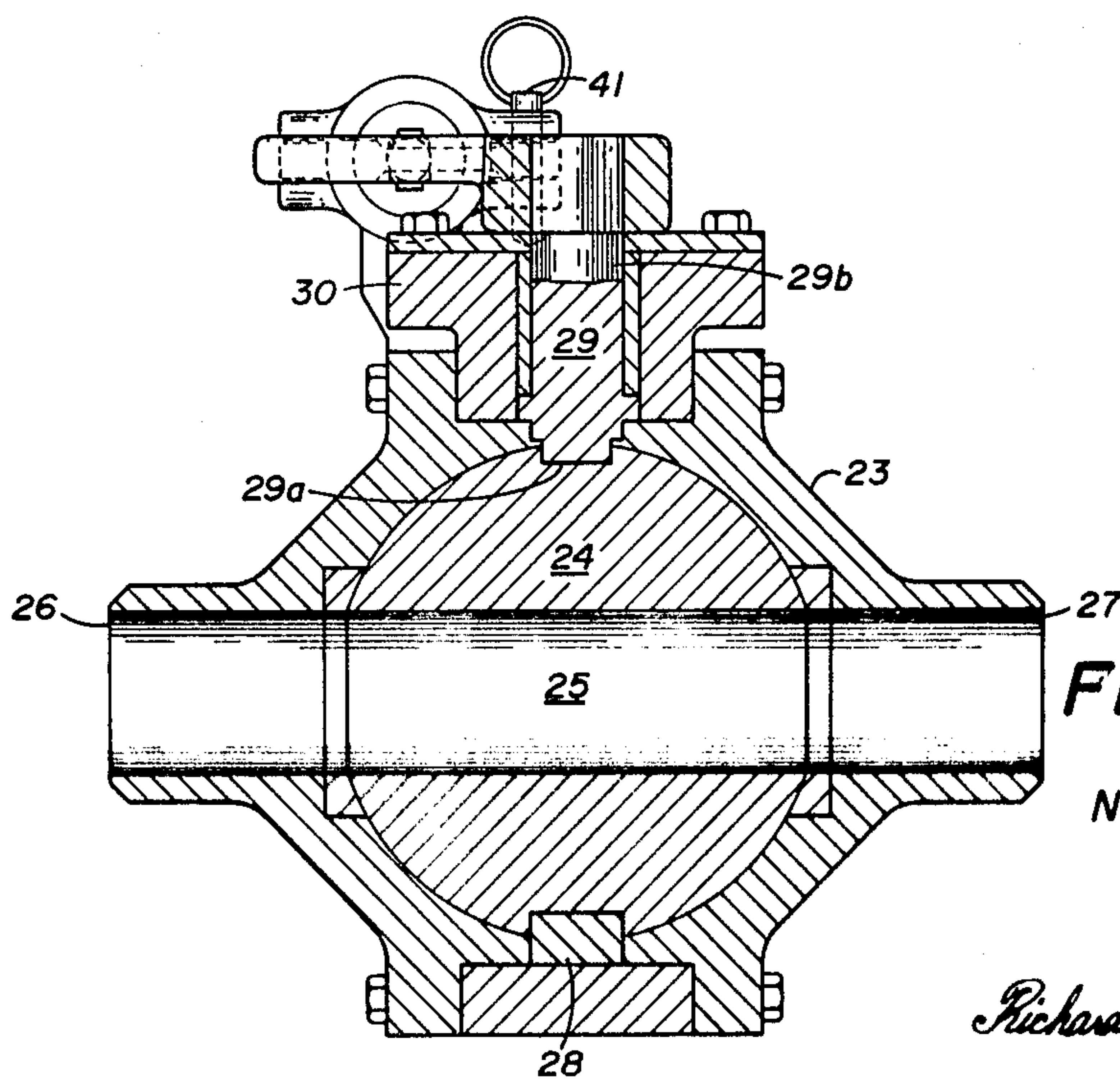


FIG. 3

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PRESSURE PULSE HYDRAULIC FRACTURING FOR SUBSURFACE FORMATIONS

This invention relates to treating of subsurface formations. In another aspect, this invention relates to a novel method and apparatus for fracturing subsurface formations which are traversed by a well bore.

Various hydraulic fracturing processes are known in the art. These processes generally include the step of forcing a fracturing fluid into a formation under increasing pressures until the formation breakdown pressure is exceeded thereby causing fissures to penetrate from the well bore into the surrounding strata. This formation breakdown pressure is roughly equal to the weight of the subsurface above the fissures being formed plus the bonding force of the formation rock, and equals to about 0.6 to about 0.9 p.s.i. per foot of depth of stratum below the surface for wells at least 4,000 feet deep.

Generally, after the initial fracturing operation, the pumping continues to cause a deepening and widening of the fissures by injection of more fluid therein.

While it is generally desirable to open a plurality of fractures in a selected stratum, the above-described hydraulic fracturing processes generally are efficient to open only a few fractures at most, and usually only one relatively large horizontal fracture. Thus, when an incipient fracture begins to open, the fluid enters and the pressure decreases so that there is a decreased tendency to open other fractures. Because of this disadvantage, several attempts have been made to develop hydraulic fracturing techniques utilizing either a "water hammer" effect to transmit a relatively large hydraulic shock against the face of the formation to be fractured and/or a series of pressure pulses to accomplish the fracturing. These attempts have generally been less than satisfactory because (1) they fail to provide a splintering action upon the face of the formation and to thereby effect a plurality of relatively small fractures radiating from the well bore; and/or (2) they cause damage to piping and equipment due to the hydraulic hammer force therein.

Generally, prior art techniques of hydraulic fracturing do not yield a plurality of relatively small fractures in the formation because of the inability to transmit a tremendous overburden pressure to the formation once the formation fracture pressure has been reached. This is generally necessary in order to transmit a shattering or fracturing effect to the formation.

Therefore, one object of this invention is to provide a novel method and means of hydraulically fracturing subterranean formations.

Another object of this invention is to provide a hydraulic fracturing technique which will create a plurality of fractures in a subsurface formation.

A further object of this invention is to provide a hydraulic fracturing technique wherein fracturing fluid can be transmitted directly through the well casing without imparting damage thereto.

According to one embodiment of this invention, a subterranean formation is fractured by establishing a first path of fracturing fluid from a pumping zone through a flow control zone, establishing a second path of flow to the formation to be fractured from a point between the pumping zone and flow control zone, controlling the flow through the flow control zone to establish a predetermined prefracturing pressure of the fracturing fluid against the face of the formation and then instantaneously terminating the first path of flow while maintaining hydraulic fluid pumping through the pumping zone to impart a pressure impulse to the fracturing fluid against the face of the formation and cause fracturing thereof.

According to another embodiment of this invention, a rarefaction pulse is transmitted along said second path of flow following the pressure pulse transmitted according to said one embodiment, and spaced behind said pressure pulse such that it will result in a decay of the pressure pulse as it is reflected upwardly from the bottom of the formation to thereby prevent damage to piping and well equipment.

According to still a further embodiment of this invention, a novel apparatus is provided for carrying out the above described two embodiments.

This invention can be understood more easily from a study of the drawings in which:

FIG. 1 is a schematic view illustrating one embodiment of this invention;

FIG. 2 is a plan view partially in section of a suitable flow control-hammer valve which can be utilized with this invention;

FIG. 3 is a sectional view along lines 3—3 of FIG. 2; and

FIG. 4 is a plot of water hammer pressure pulse which can be imparted in accordance with this invention versus pumping rate for two types of casings.

Now referring to FIG. 1, a schematic view of a fracturing operation which can be carried out in accordance with this invention is illustrated in detail.

As illustrated, well bore 10 extends through the earth into formation 11 to be fractured. Casing 12 is held within well bore 10 by cement 13. It is noted that even though this embodiment discloses the fracturing of a formation below the end of a casing, this invention can be utilized to fracture a formation through a perforated casing.

The upper portion of casing 12 communicates with conduit 14 which in turn communicates with reservoir 16 and carries flow control-hammer valve 15 operatively positioned therein. Reservoir 16 contains a suitable fracturing fluid which can be utilized in the scope of this invention, for example, water or oil. Conduit 17 communicates between pump 18 and conduit 14 at a point between the top of casing 12 and flow control-hammer valve 15. Conduit 17 operatively communicates with pulse decay means 19 which can be a conventional accumulator such as a mechanical accumulator, or flexible hose, or a combination thereof, and the like. Conduit 20 carries check valve 21 operatively positioned therein and communicates between conduit 17 and conduit 14 as illustrated. Check valve 21 is an overpressure-bypass valve which will allow fluid to flow only from conduit 17 to conduit 14 when a predetermined pressure is built up within the conduit 17.

Pump 18 is a conventional pump means such as a positive displacement-type pumping mechanism which is conventionally used in oil well treating operations. For example, pump 18 can be one or more piston-driven positive displacement type reciprocating pump mechanisms carried by one or more trucks. Pump 18 is operatively connected to reservoir 16 via conduit 22.

Flow control-hammer valve 15 can be any suitable valving mechanism which can (1) control the steady flow of fluid therethrough and (2) be substantially instantaneously closed to thereby terminate the flow of fluid therethrough in a correspondingly substantially instantaneous manner. A suitable such valve is illustrated in FIGS. 2 and 3. As shown, valve 15 comprises a valve housing 23 having a rotatable ball 24 movably positioned therein. Rotatable ball 24 carries flow passageway 25 therethrough which is adapted to communicate between valve ports 26 and 27 when in its first position, but to stop communication therebetween when in its second position (when it is rotated approximately 90° from the position as illustrated in FIG. 3). Ball 24 is rotatably mounted between spindle 28 and actuating member 29. The lower portion 29a of actuating member 29 comprises a sharply angled periphery which fits within a matching slot in the upper portion of rotatable ball 24, as illustrated. The upper portion 29b of actuating member 29 is cylindrical in shape and is rotatably mounted through plate 30 which is attached to the upper region of housing 23. Lever 31 is fixedly attached to actuating member 29 so that its rotation through 90° will correspondingly rotate ball 24 90° within housing 23.

Lever 31 is pivotally connected to the end of piston rod 32 which in turn is connected to piston 33. Piston 33 is reciprocally mounted within cylinder 34. Escape port 35 operatively communicates through the wall of cylinder 34 for the purpose of releasing gas pressure which builds up within cylinder 34

during the instantaneous valve actuating operation. The top face of piston 33 communicates with explosion chamber 36. Explosion chamber 36 is adapted to receive explosive charge 37 which can be any suitable propellant charge known in the art which is actuated by a firing pin mechanism. Charge 37 is basically in the form of a conventional shot shell and contains a propellant charge in combination with an impact-type primer which is actuated by a firing pin. Explosive charge 37 is inserted within explosion chamber 36 until its lip 37a rests adjacent spring actuated extractor 36a. As shown, bolt 38 is pivotally mounted on pin 39 in a manner so that when in the closed position it will enclose explosion chamber 36 and firing pin 40 will be aligned with the primer of charge 37. Removable pin 41 is journaled through aperture 42 to lock bolt 38 in a closed position.

As illustrated, firing pin 40 is movably positioned in aperture 43 through the face of bolt 38, and is fixedly attached to plunger 44 which carries compression spring 45 within chamber 46 therein. L-shaped sear 47 is pivotally mounted at point 48 so that the lower leg thereof will retain plunger 44 within chamber 46 when in the safe position. The upper portion of L-shaped sear 48 is biased outwardly by the action of spring 49 which rests within indentation 50. Trigger button 51 is attached to the upper leg of L-shaped sear 47 opposite spring 49. Thus, when trigger button 51 is depressed, L-shaped sear will pivot about point 48 so the lower leg thereof releases plunger 44. This action will cause compressive spring 45 to force firing pin 40 through aperture 43 so that the tip of firing pin 40 will contact the primer of charge 37. When pressure is released from trigger button 51, spring 49 will then force L-shaped sear 47 toward its upright position. The mechanism is then cocked by pulling ring 52 which is connected to the outer end of firing pin 40 upward to compress spring 45, thereby withdrawing plunger 44 and firing pin 40 into chamber 46 until lower leg of L-shaped sear 47 is forced below the bottom of plunger 44 and retains it in the cocked position.

In operation, lever 31 of valve 15 can be manually rotated to thereby control the flow of fluid passing therethrough, and when it is desired to instantaneously close valve 15, the above-described firing mechanism is actuated.

Thus, the equipment as schematically illustrated in FIG. 1 utilizing a flow control-hammer valve such as illustrated in FIGS. 2 and 3 can be utilized to practice this invention. It has been discovered that in order to effectively increase permeability uniformly in all directions of the well bore in a subterranean formation such as formation 11, it is necessary to impart an extreme overburden pressure in excess of the fracturing pressure of the formation. The process of this invention can be utilized to effect this result.

Thus, in accordance with one embodiment of this invention, pump 18 is actuated to thereby pump fracturing fluid from reservoir 16 through conduits 22 and 17 to fill casing 12, and then upwardly through conduit 14, flow control-hammer valve 15, and back to reservoir 16. After casing 12 has filled with fluid, pump 18 is operated at a relatively constant rate to thereby cause a relatively constant flow of fracturing fluid to pass through conduits 17 and 14 between pump 18 and flow control-hammer valve 15. Next, flow control-hammer valve 15 is manipulated so that pressure will build up within conduit 17 and 14 and casing 12 to a predetermined level. This predetermined pressure corresponds to pressure of the fluid adjacent formation 11 which is near, but below the fracture pressure of the formation. This predetermined pressure is at least about 40 percent of the fracture pressure, and more preferably at least about 75 percent and most preferably at least about 90 percent of the fracture pressure of the formation. If desired, the initial pressure can be built up slightly in excess of the fracture pressure of the formation.

This initial operation will raise the pressure against formation 11 adjacent well bore 10 to a desired predetermined level, and will usually cause the "leak off" of a minor amount of fracturing fluid. Next, flow control-hammer valve 15 is instan-

taneously closed in a manner as described above. This will impart a tremendous pressure pulse to the fluid flowing in conduits 14 and 17, and contained within casing 12 and against formation 11 below casing 12. The pressure pulse will thus be transmitted along the fluid column within well bore 10 until it reaches the bottom thereof adjacent formation 11. The action of the pressure pulse impacting against formation 11 will cause fracturing thereof. The intensity of this pressure pulse will generally be a function of the volumetric flow rate of the fluid passing from pump 18 through flow control-hammer valve 15, and the diameter of casing 12. FIG. 4 is a plot of the water hammer pressure pulse (p.s.i.) which can be imparted with various pumping rates (barrels per minute) for 5 inch and 6 inch diameter casings. Thus, for example, if it is desired to create an overpressure of 1,000 pounds per square inch into a 6 inch casing a pumping rate of about 28 barrels per minute should be utilized in conduits 17 and 14 between the pump 18 and flow control-hammer valve 15.

The instantaneous closing of flow control-hammer valve 15 will not only impart a tremendous pressure impulse down casing 12, but also back toward pump 18 through conduit 17. This pulse will be decayed first by the action of pulse decay means 19, which is illustrated as a conventional accumulator device. Alternatively, the pulse can be absorbed by a flexible hose alone or in combination with an accumulator or by any other such suitable device. In addition, when the pressure adjacent the outlet of pump 18, and within conduit 20 reaches a maximum predetermined pressure generally a few pounds/square inch above the operating pressure of pump 18, e.g., about 25-50 p.s.i., check valve 21 will open and allow fluid to pass therethrough. These actions will protect pump 18 from the pressure pulse imparted to the system by the closing of flow control-hammer valve 15.

Flow control-hammer valve 15 can remain closed for any desired period of time, but it is generally preferable to maintain valve 15 closed for a period of less than 1 second to about 10 minutes. The opening of valve 15 will again result in the continuous flow through conduits 17 and 14 between pump 18 and flow control-hammer valve 15. The pressure pulse can be imparted to the fluid within well bore 10 as often as desired until the requisite fracturing occurs. In some operations wherein the initial pressure pulse or pulses imparted to the formation opens a rather large incipient fracture communicating with the well bore, it may be desirable to temporarily block this fracture by conventional means, such as filling with blocking agents, including salt and the like, before imparting additional pressure pulses thereto to thereby impart a relatively large number of fractures to the face of the formation communicating with the well bore. This instance will occur when the incipient fracture is very weak and easily opened with a minimum of pressure therein.

In accordance with another embodiment of this invention, a rarefaction pulse is transmitted to the fluid in the casing 12 after the pressure pulse has traveled a distance which corresponds to about the length and preferably about twice the length of the formation 11 to be fractured which is traversed by well bore 10. This rarefaction pulse will be of a magnitude to substantially decay and preferably cancel the pressure pulse which is reflected from the bottom of well bore 10 and thereby prevent damage to casing 12 and the pumping equipment. Since the pressure pulse which is reflected from the bottom of the well bore 10 can be as great as twice the magnitude of the pressure pulse transmitted to the well bore, it can cause excessive strain and possibly destruction to the casing and equipment if it is allowed to pass therethrough. Thus, when the rarefaction pulse follows the pressure pulse at a distance substantially equal to the length f of formation 11 which is traversed by well bore 10, then it will meet with and decay the reflected pulse from the lower end of well bore 10 at the point of approximately $f/2$ from the bottom of well bore 10. However, if the rarefaction pulse follows the pressure pulse by approximately twice the length f of the formation to be fractured which is traversed by well bore 10, then the rarefaction pulse

will meet with the pulse reflected from the bottom of well bore 10 after it has traveled about the distance f from the bottom thereof, i.e., at approximately the point of termination of casing 12. This action will serve to cancel or decay the pressure pulse before it is reflected upward within casing 12 and the rest of the equipment. The rarefaction pulse will decay the reflected pulse to a value of no greater than the magnitude of the initial pressure pulse.

Preferably, this rarefaction pulse is transmitted by the effect of the proper positioning of pulse decay means 19 within conduit 17. Thus, whenever the pressure pulse is transmitted from conduit 17 to pulse decay means 19, it will be canceled to form a rarefaction pulse which is reflected back through conduit 17 and into the fluid contained within the casing 12. If the length between the top of casing 12 to pulse decay means 19 is approximately $f/2$, then the rarefaction pulse which is transmitted from pulse decay means 19 will follow the pressure pulse from flow control-hammer valve 15 at a distance of approximately f . In the preferred embodiment of this invention, the distance from the top of casing 12 to pulse decay means 19 is approximately equal to f such that the rarefaction pulse will follow the pressure pulse through fluid in casing 12 at a distance of approximately $2f$. Thus, in the latter instance, the pressure pulse which has been reflected from the bottom of well bore 10 will be met and decayed by the rarefaction pulse at about the time it has reached the bottom end of casing 12.

It is noted that various parameters can be utilized in practicing the process of this invention. As stated, it is generally desirable to maintain an initial pressure of the fluid against the formation 11 at value slightly less than the fracture pressure thereof. In addition, the intensity of this fracture pulse can be varied in accordance with the volumetric rate of flow of fluid through conduits 17 and 14, i.e., the speed of pump 18. The intensity of the fracture pulse will vary of course, with the type of rock contained within formation 11, but for most operations it is preferably at least 1,000 p.s.i. greater than the fracture pressure of the formation. These pressure pulses can be calculated as a function of flow rate and casing diameter as illustrated in FIG. 4. It is noted that the pumping rate of fluid passed through conduits 17 and 14 in accordance with this invention, can vary from about 1 barrel per minute to about 200 barrels per minute, and in most operations will be in the range of about 10 to about 100 barrels per minute.

The following example is given solely for the purpose of illustrating this invention and is not intended to limit the scope thereof.

EXAMPLE

The apparatus as illustrated in the drawings is initially connected to a well which is 6,000 feet deep and has a 0.6 fracture gradient, or a fracture pressure of approximately 3,600 p.s.i. A 6-inch inside diameter casing is cemented in the well bore to a point of 5,980 feet, a point at which the formation begins to which it is desired to fracture. Accordingly, the distance between the top of the casing and the pulse decay means (accumulator) along conduit 17 is approximately 20 feet. Initially, pump 18 is actuated to circulate fluid through conduits 17 and 14 at a rate of 40 barrels per minute. Flow control-hammer valve 15 is manually closed slightly to adjust the pressure of the fluid within well bore 10 adjacent formation 11 to about 3,100 p.s.i. or about 500 p.s.i. below the fracturing pressure. Next, trigger button 51 is depressed to cause explosive charge 37 to force lever 31 to flow control-hammer valve 15 to instantaneously close. This causes a 1,500 p.s.i. pressure pulse to be propagated down the 6 inch casing at about 4,700 feet per second. This action instantaneously imparts a pressure of 1,000 p.s.i. in excess of the minimum fracture pressure to the formation. This overpressure causes multiple fractures to radiate from the well bore in several planes within the formation. In addition, the rarefaction pulse which is initiated by the action of accumulator 19 decays the reflected pressure pulse to a value no greater than 1,500 p.s.i. at approximately

the depth of 5,980 feet (a point adjacent the lower end of the 6-inch I.D. casing). Lever 31 of flow control-hammer valve 15 is rotated to its open position approximately 30 seconds after the instantaneous closing operation. This process can be repeated as many times as desired to generate the random direction fractures which radiate from well bore 10 into the formation 11. Next, after the fractures are initiated, this operation is followed by a conventional fracture pumping operation to extend the multiple fractures. The fracturing fluid is slowly pumped into the formation which contains suitable propping agents and will act to extend the initial fractures and pop them open to form a highly permeable formation.

While this invention has been described in relation to its preferred embodiments it is to be understood that various modifications thereof will now be apparent to one skilled in the art upon reading the specification, and it is intended to cover such modifications as fall within the scope of the appended claims.

I claim:

1. A method of fracturing a subterranean formation penetrated by a well bore comprising:

- a. establishing a first path of flow of a fracturing fluid from a pumping zone through a flow control zone;
 - b. establishing a second path of flow of said fracturing fluid from a point between said pumping zone and said flow control zone to said formation to be fractured;
 - c. controlling the flow of said fracturing fluid through said flow control zone to thereby establish a predetermined prefractioning pressure against said formation to be fractured;
 - d. instantaneously terminating said first path of flow through said flow control zone while maintaining said flow through said pumping zone to yield a fracturing pulse which is transmitted down said second path of flow and against said formation to cause the fracturing thereof; and
 - e. transmitting a rarefaction pulse down said second path of flow to thereby decay said fracturing pulse within said formation after said fracturing.
2. The method of claim 1 wherein said predetermined pressure is slightly below the fracture pressure of said formation.
3. The method of claim 2 wherein said predetermined pressure is at least about 40 percent of the fracture pressure of said formation.
4. The method of claim 1 wherein said pumping zone and said flow control zone are located above the surface of the earth.

5. A method of fracturing a subterranean formation penetrated by a well bore comprising:

- a. establishing a first path of flow of a fracturing fluid from a pumping zone through flow control zone;
- b. establishing a second path of flow of flow said fracturing fluid from a point between said pumping zone and said flow control zone to said formation to be fractured;
- c. controlling the flow of said fracturing fluid through said flow control zone to thereby establish a predetermined prefractioning pressure against said formation to be fractured;
- d. instantaneously terminating said first path of flow through said flow control zone while maintaining said flow through said pumping zone to yield a fracturing pulse which is transmitted down said second path of flow and against said formation to cause the fracturing thereof; and
- e. imparting a rarefaction pulse to the fluid in said second path of flow which is sufficient to cause decay of said fracturing pulse in a manner so that said rarefaction pulse follows said fracturing pulse a spaced linear distance that is at least the length of said formation to be fractured which is traversed by said well bore.

6. The method of claim 5 wherein said spaced linear distance is about twice the length of said formation to be fractured which is traversed by said well bore.

7. The method of claim 5 wherein said rarefaction pulse is formed by decaying the pressure pulse emitted toward said pump by said instantaneous terminating at a distance from said point to said pump which corresponds to at least one-half of said linear distance.

8. The method of claim 5 wherein said decay occurs in said first stream at a distance from said point to said pump which corresponds to about the length of said formation to be fractured which is traversed by said well bore.

9. An apparatus positioned upon the surface of the earth for fracturing a subsurface formation penetrated by a well bore comprising:

- a. a pumping means for imparting a constant motion to a fracturing fluid;
- b. a valve means for controlling flow of said fracturing fluid, and adapted to instantaneously terminate flow of said fracturing fluid therethrough to thereby impart a fracturing pulse in said fracturing fluid;
- c. first conduit means communicating between the outlet of said pumping means and the inlet of said valve means;
- d. second conduit means communicating between said first conduit means and said well bore at a point between said pumping means and said valve means; and
- e. pressure decay means positioned in said first conduit means at a point between said second conduit means and said pumping means to impart a rarefaction pulse in said fracturing fluid sufficient to decay said fracturing pulse.

10. The apparatus of claim 9 further comprising:

- a. a reservoir means for holding a supply of the fracturing fluid;
- b. third conduit means communicating between said reservoir means and the inlet of said pumping means; and
- c. fourth conduit means communicating between the outlet of said valve means and said reservoir means.

11. The apparatus of claim 10 further comprising a fifth conduit means communicating between said reservoir and a point in said first conduit means between said pumping means and said second conduit means, and having a check valve means operatively positioned therein to allow fluid flow therethrough only from the first conduit to said reservoir in response to said fracturing pulse.

12. The apparatus of claim 11 wherein the length of said first conduit means from the intersection of said second conduit means with said first conduit means to said pressure decay means is at least about one-half the length to about the length of said formation to be fractured which is traversed by said well bore.

13. An apparatus for fracturing a subsurface formation penetrated by a well bore comprising:

- a. a pumping means for imparting a constant motion to a fracturing fluid;
- b. a valve means for controlling fluid of said fracturing fluid, and adapted to instantaneously terminate flow of said fracturing fluid therethrough;
- c. a first conduit means communicating between the outlet of said pumping means and the inlet of said valve means;
- d. second conduit means communicating between said first conduit means and said well bore at a point between said pumping means and said valve means; and
- e. a pressure decay means positioned in said first conduit means at a point between said second conduit means and said pumping means, and wherein the length of said first conduit means from the intersection of said second conduit means with said first conduit means to said pressure decay means is at least about one-half the length to about the length of said formation to be fractured, which is traversed by said well bore.