Dec. 1, 1959 D. S. HULSE 2,915,122

FRACTURING PROCESS WITH SUPERIMPOSED CYCLIC PRESSURE

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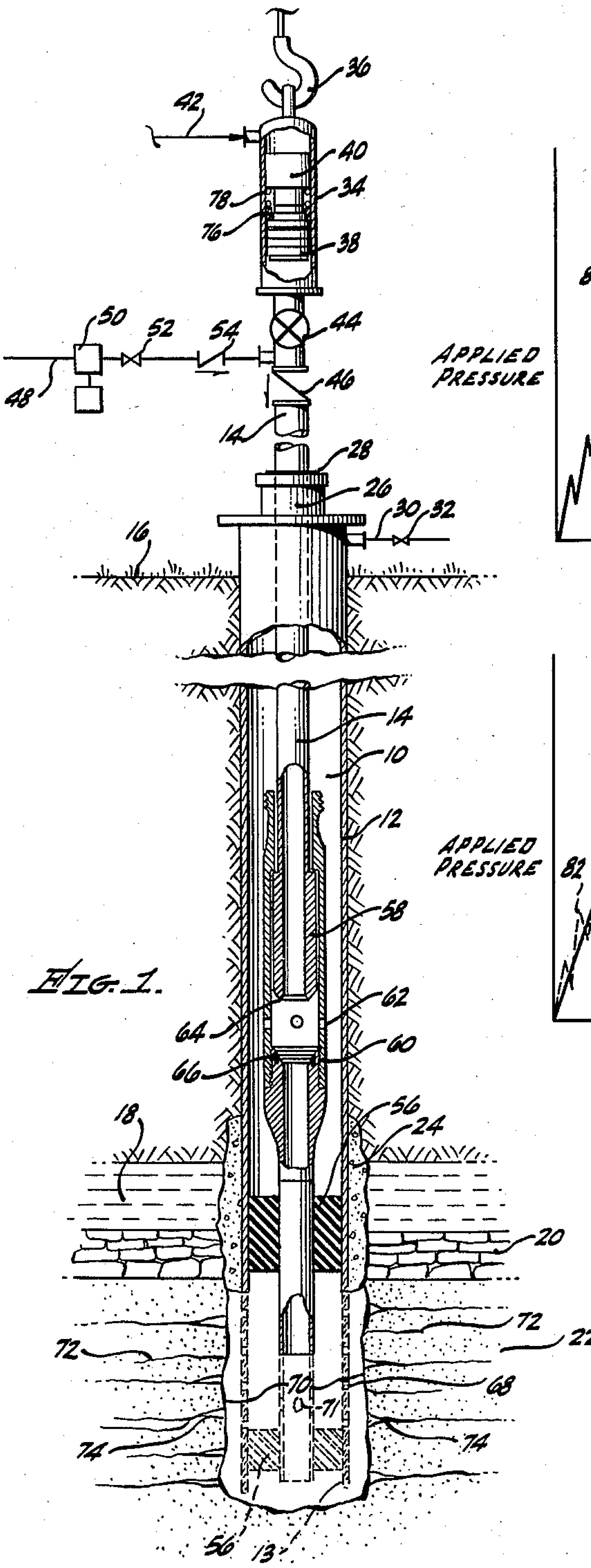

FIG. 1.

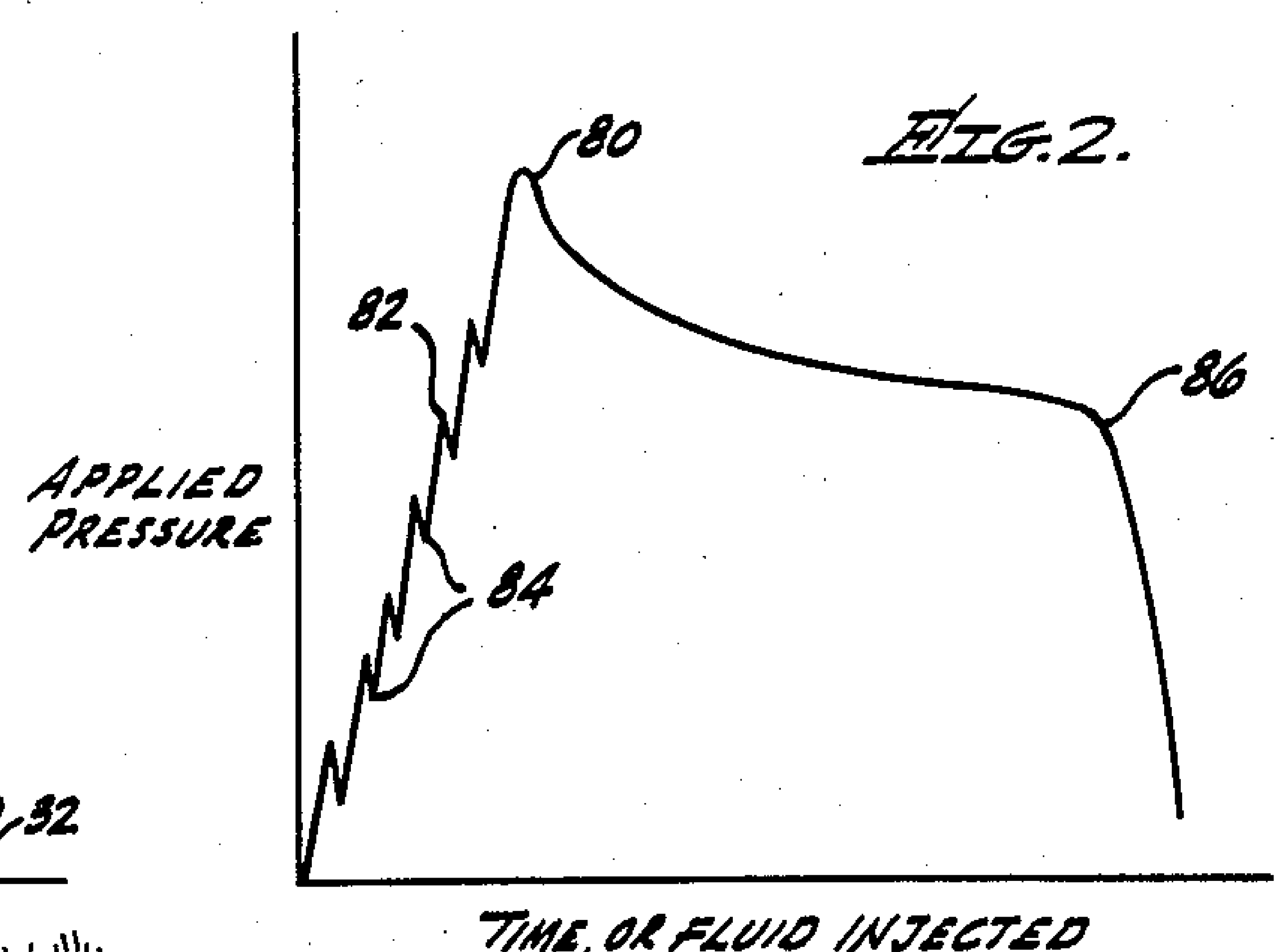

FIG. 2.

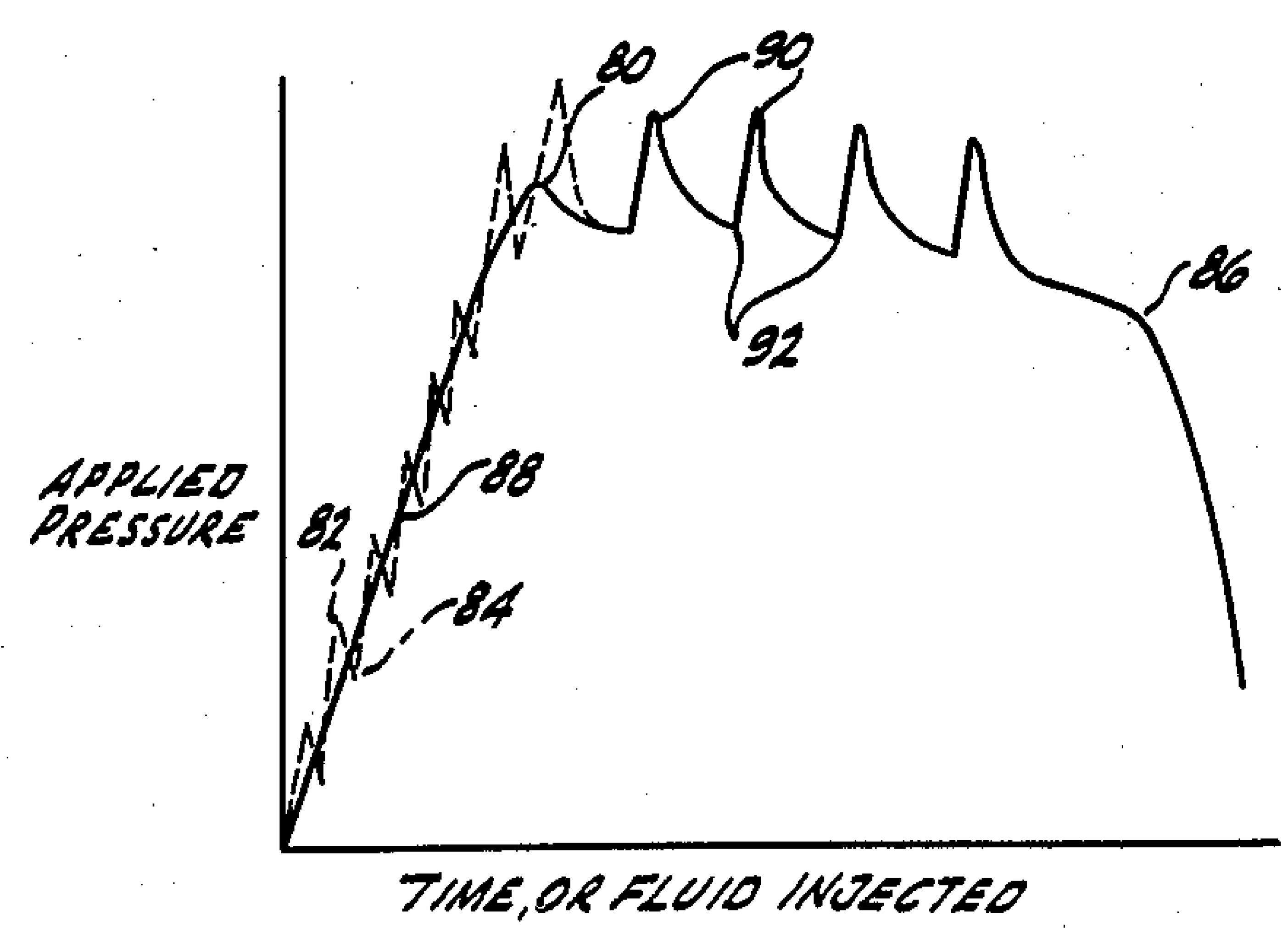

FIG. 3.

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FRACTURING PROCESS WITH SUPERIMPOSED CYCLIC PRESSURE

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7 Claims. (Cl. 166—42)

This invention relates to the treating of subterranean formations, such as those containing crude petroleum or other valuable fluids, by the application of hydraulic pressure. This invention particularly relates to an improved method for hydraulically fracturing such underground formations in which successive shock pressure waves are superimposed upon the applied hydraulic pressure either before or after the formation breakdown pressure is reached, or both. This procedure has been found to result in the formation of a large plurality of underground fractures rather than one or only a few, and to result also in the injection of larger quantities of fluid and propping agent into the fractured formation than heretofore obtainable.

There has been recently developed a well-treating process for hydraulically fracturing selected underground geologic strata by the application of relatively high hydraulic pressures. This process is referred to as the "Hydrafrac" process and the object is to increase the fluid permeability of selected underground formations so that fluid can be injected into or produced from them at greater rates. These hydraulic processes are described sufficiently in U.S. Patents No. 2,596,843, 2,596,844 and 2,596,845 and accordingly they will only be briefly described here.

In general, the aforesaid "Hydrafrac" process consists of injecting a gel or "low penetrating" fluid, such as one having a high viscosity or a low penetration rate or which forms a filter cake, into the well bore where it is positioned adjacent the formation to be treated. A high hydraulic pressure is generated by pumping the fluid into the bore faster than it penetrates the formation. Many specific liquids have before been disclosed in the literature which have the foregoing properties so as to adapt them for this particular purpose. The hydraulic pressure is increased in this manner over a period of from 1–10 minutes to a value which exceeds the "formation breakdown pressure." At this time the overburden is lifted causing fissures to penetrate from the bore into the surrounding strata and the fluid then flows through these fissures. The formation breakdown pressure is roughly equal to the weight of the rock above the fissures being formed plus the bonding force of the rock itself. For wells deeper than about 4,000 feet, this breakdown pressure ranges between about 0.6 and about 0.9 p.s.i. (lbs. per square inch) per foot of depth of the stratum below the surface. The low penetrating fluid desirably contains propping agents such as sand grains of selected size which hold the fissures open after release of the applied hydraulic pressure. Pumping continues after "breakdown" for a period of from 30 to 100 minutes to deepen the fissures by injection of more fluid. After the fracture has been completed a "gel breaker" is usually injected through the bore into the formation to reduce the viscosity of the "low penetrating" fluid and thereby facilitate its removal from the formation and the bore. The high pressure is then released and the connate fluid, such as petroleum, then flows through the newly formed fissures into the bore at substantially increased rates, or an injection fluid can flow into the formation at increased rates in the case of an injection well.

This system for permeability formation treating is a marked improvement over nitroglycerin detonation because it is operable in cased perforated bore holes. It is cheaper and quicker than lateral drilling from the bore hole, and it is superior to acid treating because it is not restricted to the treatment of calcareous strata.

The foregoing process as generally described usually results in the formation and opening of at most a few and generally only one relatively large horizontal fracture. This is due to the fact that when one weak spot or incipient fracture begins to give way the fluid enters and the pressure decreases so that there is a decreased tendency then to open additional features. This is a disadvantage, and the formation of many small fissures is much more desirable, particularly in the fracturing of relatively thick formations. The present invention therefore relates to an improvement in the hydraulic fracturing process in which a greater plurality of relatively small fractures is formed, a greater quantity of fracturing fluid may be injected into the formation, and the resulting fractured formation is capable of producing substantially increased quantities of valuable fluid or receiving greater quantities of injection fluid than when the conventional fracturing procedure is followed.

It is therefore a primary object of this invention to provide an improved hydraulic fracturing procedure for underground strata in which a series of pressure shocks is applied during the build-up of hydraulic pressure to the formation breakdown pressure so as to weaken and open a plurality of fractures in a selected stratum.

It is also an object of this invention to improve the hydraulic fracturing process by applying a succession of pressure shocks to the fracturing fluid after the formation breakdown pressure has been reached so as to increase the quantity of low penetrating fluid injected into the strata and to generate deeper fissures in these formations.

It is also an object of this invention to provide in the hydraulic fracturing process a relatively continuous series of shock pressures during pressure build-up to the formation breakdown pressure as well as after the breakdown pressure is reached to produce a great plurality of deep fissures in the formation being treated.

It is an additional object of this invention to provide a hydraulic fracturing process in which normal well fluids are purged or displaced from adjacent the area by flowing the low penetrating fluid upwardly through the bore hole prior to building up the high pressures necessary to fracture the formation.

Other objects and advantages of the present invention will become apparent to those skilled in the art as the description and illustration thereof proceed.

Briefly the present invention comprises an improved hydraulic fracturing process for the treatment of underground fluid-permeable or fluid-containing strata in which any of the conventional low penetrating fluids or gels are pumped into the bore and positioned adjacent to the strata to be treated. If desired, a special valve hereinafter described is opened near the bottom of the tubing string and part of the low penetrating fluid is passed upwardly through the annulus to purge normal well fluids from adjacent the stratum to be treated. This valve is then closed and the hydraulic pressure is increased by pumping a low penetrating fluid into the bore hole at a rate which is higher than the rate at which the unfractured stratum can accept fluid flow. This pressure build-up is continued until it reaches a value adjacent the stratum face sufficient to lift the formation causing cracks or fissures to open from the bore back into the stratum. Following formation fracture the pressure drops somewhat from the maximum value and a substantial quantity of the low penetrating fluid is pumped into the newly opened fissures so as to enlarge them and cause them to progress a substantial distance into the stratum from the bore.

The specific improvement of this invention lies in the modification of this part of the well treating process to incorporate a series of applied pressure shocks to the column of fluid in the well bore in such a way that they are superimposed upon the applied hydraulic pressure as described above.

In one modification of the invention, a plurality of mechanically induced pressure shocks is applied directly to the low penetrating fluid being pumped into the well head. The formation breakdown pressure is approached gradually by pumping a continuous stream of low penetrating liquid into the well, and with the pressure shocks being superimposed on the gradually increasing pumping pressure, the breakdown pressure is actually approached in a series of steps in which the pressure is rapidly increased, then lowered slightly, then rapidly increased to a higher value, then lowered to a value higher than the previous low, etc. until the actual breakdown pressure is attained. Preferably this build-up continues over a somewhat longer period than normal, such as from about 5–30 minutes.

The pressure shocks are applied directly to the column of liquid at the well head by means of an air hammer or a piston or other suitable apparatus. This pressure shock is transmitted without substantial loss or attenuation downwardly through the column of liquid standing in the tubing string and is applied directly to the exposed face of the stratum being treated. During the hydraulic pressure build-up the series of shock waves apparently applies high local stress to all of the incipient fractures in the stratum so as to weaken them. Then when the formation breakdown pressure is finally attained, a great many of the then weakened fractures open instead of only one or a few such fractures. These results have been indicated through the physical testing of the present invention wherein substantially increased quantities of fluid are injected into the formation and subsequently increased quantities of product fluids flow therefrom into the bore.

In another modification of this invention, the hydraulic pressure is built up to the formation breakdown pressure in the normal way by pumping liquid into the bore. When the formation breakdown pressure is reached and the fissures form, the series of pressure shocks is begun and continued during the flow of low penetrating fluid into the open fissures. In this way the fractures which are opened are greatly deepened and extended to greater distances from the bore into the formation, or the required time for the same degree of fissure deepening is considerably reduced. This is indicated by a substantial increase in the quantity of low penetrating fluid which can be injected during the treatment.

A preferred third modification of the present invention lies in combining the two modifications described above so as to secure the advantage of each modification and whereby each unexpectedly enhances the results of the other. Thus when the low penetrating fluid pressure increase is begun the shock wave application is also begun at the well head and continued substantially throughout the entire period of pressure application, that is, during the pressure build-up to the formation breakdown pressure as well as after this pressure is reached and while fluid injection is continued. In this modification not only is a greater number of stratum fissures formed because of the weakening of all of the incipient fractures, but they are then extended greater distances into the stratum by the shock wave application. The overall result of such a treatment is a treated well whose fluid productivity is measurably increased by amounts of the order of 25% to about 100% greater than that of a bore treated by the conventional hydraulic fracturing methods.

In practicing the process of the invention, any of the conventional low penetrating fluids can be used so as to build up a pressure to the formation breakdown value. Also any appropriate "gel breaker" or other fluids specifically adapted to facilitate removal of, or other action on, the "low penetrating fluid" may also be used in the process of this invention. Such fluids are all described in the art referred to previously. The low penetrating fluid may be modified to contain formation propping agents to facilitate the maintenance of open fissures after removal of the applied hydraulic pressures. Such agents and the manner of their use are also described in the art.

The process of the apparatus in this invention will be more readily understood by reference to the accompanying drawings in which:

Figure 1 shows an elevation view in a partial cross section of a cased well bore and the tubing string with a single packer in which the process of this invention is effected, a double packer for isolating a selected stratum interval for treatment also being shown,

Figure 2 is a graphic illustration of the application of hydraulic pressure to the formation breakdown value together with applied shock waves, and

Figure 3 shows shock wave application after the formation breakdown value is reached, as well as the preferred modification in which the shock waves are applied both before and after the stratum is fractured.

Referring now to more particularly Figure 1, well bore **10** is provided with casing **12** and tubing string **14** extending downwardly from ground level **16** through several non-permeable strata **18** and **20** into a fluid-permeable fluid-containing stratum **22**. A water shut-off in the form of a concrete seal **24** surrounds the lower end of casing **12** and prevents the loss of valuable fluids upwardly around the outside of the casing. A slotted liner **13** may be added if desired.

The upper end of casing **12** is provided with lubricator **26** having a tubing seal **28** through which tubing string **14** extends. Line **30** provided with valve **32** opens from the casing head as shown. At the upper end of tubing string **14** is provided hammer **34** supported by means **36** from the derrick. Hammer **34**, for example, consists of a cylinder containing lower piston **38** and upper piston **40**. Inlet line **42** permits the introduction of fluid under pressure as a series of impulses thereby causing upper piston **40** to apply a series of direct impacts against lower piston **38**. Air or water or oil or any suitable fluid can be used to drive piston **40**.

The hammer **34** communicates directly at its lower end with the top of tubing string **14** through shut-off valve **44** and second check valve **46**. The fracturing liquid is pumped by means of pump **50** through line **48**, shut-off valve **52** and first check valve **54** into tubing string **14** at a point between valves **44** and **46**.

The bottom of tubing string **14** is provided with packer **56** which seals the outside surface of the tubing string against the inside surface of the casing adjacent its lower end. When treating a stratum at intermediate depths in a well bore packers should be provided both above and below the strata to be treated as shown by broken lines. In such a case apertures **71** are provided as an exit for the low penetrating liquid which is pumped down the tubing string. In any event, with the packer in place, the tubing string is lifted a distance sufficient to raise inner valve element **58** with respect to outer valve element **60** to exposed one or more rows of apertures **62** in the outer valve element. The fracturing fluid flow is then begun by opening valve **52** and starting pump **50**, and with shut-off valve **44** closed. The fluid flows through check valves **54** and **46** downwardly through tubing string **14** and through apertures **62** so as to purge from the annulus at least a part of the fluids normally present there. Preferably, sufficient fluid is allowed to flow so as to fill the annulus with oil or other liquid to a substantial depth above the top of packer **56**. The annulus may if desired be filled up to outlet line **30**. In any case, the liquid column in the annulus acts as a support for tubing **14** and packer **56** during application of extreme pressure shocks. After the annulus is filled to the desired extent, the tubing string is then lowered whereby the inner valve element **58** descends so as to cover apertures **62** and to seat its lower edge **64** against a soft metal insert **66** disposed as shown in Figure 1.

The above-described valve, in addition to being used as described as a means of readily adding liquid to the annulus **10** after packer **56** is set in lower end of casing **12**, is also used in the displacement of the supporting liquid from the annulus by the injection of compressed gas into the annulus at the top via line **30** after the fracturing job is completed. Also, because of the travel of inner element **58** in valve body **60**, it may be used to jar packer **56** loose in case it sticks in the casing after fracturing job is complete.

The flow of fracturing fluid is then continued into space **68** opposite permeable stratum **22**. The pressure is then increased by operating pump **50** at a relatively high rate so as to deliver more fluid than can normally flow into permeable stratum **22** through its exposed face **70**. The pressure therefore rises toward the formation breakdown value at which point the plurality of the incipient fissures **72** open as at **74** and progress inwardly along the weakened fracture planes into formation **22**.

As discussed briefly above, this result is obtained by employing either one or both of the specific modifications described and in which a series of pressure shock waves is applied downwardly through the liquid column by the means illustrated in Figure 1. With the liquid pressure applied by means of pump **50** acting downwardly through check valves **54** and **46** and tubing string **14**, shut-off valve **44** is opened which causes the fluid pressure to force lower piston **38** upwardly against stop **76**. Upper piston **40** may be maintained normally in an elevated position by means of a spring **78**. The injection of actuating fluid through line **42** in a series of pulses causes upper piston **40** to reciprocate and apply a series of direct impact shocks against lower piston **38**. This in turn applies a series of pressure shock waves directly to the liquid column in tubing string **14** whereby the shock waves are transmitted downwardly through valves **44** and **46** and tubing string **14** to the face **70** of permeable stratum **22**. After each shock wave is applied the reverse flow of liquid upwardly through tubing string **14** is prevented by means of check valve **46**, although the continued injection of fracturing fluid is permitted by check valve **54** thereby returning lower piston against stop **76**. This sequence of steps and the apparatus described permits the carrying out of any of the three process modifications briefly described above.

In Figures 2 and 3 are shown plots of the hydraulic pressure existing at the well head at various times during the well treatment process, or as a function of the quantity of liquid injected during the process.

With particular reference to Figure 2, the first modification of the injection is illustrated in which applied pressure shocks are used during the build up of pressure from the beginning until the formation breakdown pressure is reached at point **80**. The successive pressure peaks **82** and pressure lows **84** during the pressure build-up are shown. In this way a substantially increased number of incipient fractures are weakened whereby each is permitted to open when the formation breakdown pressure at **80** is finally reached. After the formation breakdown pressure is attained, the pressure drops somewhat during the increased flow of liquid into the opened fractures. This continues until the applied pressure is released as at point **86** and then the pressure rapidly falls.

In Figure 3 the pressure variations in the second and third modifications of this invention are shown. In the second modification the normal pressure build-up follows linear portion **88** to the formation breakdown pressure at **80**, following which the pressure shocks are applied so as to produce a series of pressure peaks **90** and pressure lows **92**. This continues until the pressure is released at point **86** as before and then the pressure decreases. In the third modification, the pressure shock series is employed both during the pressure build-up and after breakdown as described in Figure 2 and pressure peaks **82** and pressure lows **84** appear during this initial period of the process.

The application of the modifications of this invention to actual producing wells is as described below: Of course, the same procedure is applicable to injection wells also.

Example 1

The conventional hydraulic fracturing technique was applied to a subsurface oil producing formation which before treatment had a relatively low production rate of 17 barrels per day. When the conventional hydraulic fracturing treatment using gelled gasoline as the low penetrating fluid was employed and the well cleaned following the treatment, the production rate increased to a value of 31 barrels per day. This constitutes an 82% increase in productivity.

Example 2

In the same oil field in a well penetrating the same formation, the improved process of this invention was employed in its first modification. The previous productivity of this well had been 9.5 barrels per day. Gelled gasoline was pumped into the well bore as the low penetrating fluid over a period of about 10 minutes, during which time the applied pressure was built up to the formation breakdown value and pressure shock waves were applied at a rate of about 15 per minute. Each of these shock waves when applied increased the then existing fluid pressure at the well head by an amount approximately 700 p.s.i.g. Following attainment of the formation breakdown pressure the usual hydraulic fracturing techniques were followed and the well was again placed on production. The equilibrium production rate of the thus treated well was measured at 21 barrels per day. This constitutes a 121% productivity increase, which in turn is an increase approximately 47% greater than that experienced in Example 1.

Example 3

In a third well penetrating the same formation in the same oil field as in the previous two examples, the production rate prior to treatment was 19 barrels a day. Gelled gasoline was again employed as the low penetrating fluid, the conventional technique was employed to raise the pressure of the fluid to the formation breakdown value, and thereafter a series of 700 p.s.i. shock waves at about 15 per minute was maintained during the injection period. Following pressure release the equilibrium productivity of the thus treated well was found to be 37 barrels per day, or a 95% increase over the untreated value.

Example 4

In a fourth well in the same field and stratum penetrated by the wells in Examples 1, 2, and 3, the original productivity was 8 barrels a day. Gelled gasoline was again employed as the low penetrating fluid. During the 10 minute interval while the formation breakdown pressure was being approached, pressure shocks of about 700 p.s.i. were applied at about 15 per minute directly to the fluid being injected until the formation breakdown pressure was attained. The pressure shocks were then continued for approximately 15 minutes during which time a substantial fluid injection into the fractured stratum was noted. The gel breaker liquid was introduced after the pressure release and the well was returned to production. The equilibrium production rate was measured at 31 barrels a day; this amounts to an increase of 184%.

Example 5

The procedures of the previous example were applied to a well 4200 feet deep to fracture the permeable formation at that level and simultaneously to remove a paraffin deposit accumulated from waxy crude which had all but blocked the borehole opposite the strata. In this operation the low penetrating fluid used gas oil which was pumped through a steam heated heat exchanger. The oil was heated to about 350° F. and pumped into the hole. The pressure was first raised to about 800 p.s.i. to force the hot oil through the wax cake into the strata for about 10–15 minutes, then it was released through the tubing causing the well to flow. This was repeated several times until the strata appeared to take substantial quantities of gas oil at the 800 p.s.i. applied pressure indicating that the paraffin block had been broken. Following these steps, the process of this invention as illustrated in the above Example 4 was applied building up gradually to about 3000 p.s.i. The pressure shocks applied here were about 600 p.s.i. This treatment not only removed the paraffin block, but also effected a fracturing of the formation. The well productivity increased about 60%, i.e. from about 20 barrels per day to over about 100 barrels per day, leveling off at about 32 barrels per day.

Example 6

The well in Example 1 was produced for about 30 days at the 31 barrels per day rate. In an attempt to determine the effect of a second application of conventional hydraulic fracturing, the previous treatment was repeated at the applied pressures previously used. Although at this pressure additional fluid entered the strata, no pressure break characteristic of further formation fracture was noted. Replacing the well on production substantiated this by showing the same productivity.

This well was then treated using the pressure shock treatment described in Example 4. The pressure was built up to the breakdown value in about 10 minutes during which 750 p.s.i. shock pressures were applied at the rate of 50 per minute. The new breakdown pressure value was found to be 250 p.s.i. below the first fracture, indicating the effective weakening of incipient fractures. This application was continued after the breakdown. After the well was replaced on production, the equilibrium production rate was determined to be 38 barrels per day, i.e. a further increase of about 40% above the original conventional treatment. It is believed that the final production rate would have been greater than 38 barrels per day had the pressure shock treatment been applied in the first instance because of a greater incipient fracture weakening effect in the absence of any previously fractured strata.

The startling increase in productivity of these wells over the productivity obtained by the conventional "Hydrafrac" technique is attributed to the application of pressure shocks before or after, or both before and after, the attainment of the formation breakdown pressure. Many of the numerous incipient fractures or weak points which exist in the fluid-producing strata are weakened and actually fractured by the process of this invention and substantially increased quantities of fluids are injected into these fractures deepening them well back into the stratum. Thus the permeability increase is substantially greater and the productivity of the well is materially improved.

The pressure shocks applied in the process of this invention are usually between about 50 and 5000 p.s.i. above the applied hydraulic pressure. The frequency of application is preferably between about 5 and 500 per minute although the heavier shocks may be applied at frequencies as low as about one per minute and the lighter shocks may be applied at frequencies as high as about 1000 per minute. The heavy low frequency shocks are preferred because of the tremendous inertia of the system. The so-called sonic and supersonic frequencies beginning at about 3000 cycles per minute are inapplicable for this reason and appear to have little effect in the practice of this invention.

A particular embodiment of the present invention has been hereinabove described in considerable detail by way of illustration. It should be understood that various other modifications and adaptations thereof may be made by those skilled in this particular art without departing from the spirit and scope of this invention as set forth in the appended claims.

I claim:

1. In a process for hydraulically fracturing a subterranean formation penetrated by a well bore wherein a fracturing liquid is pumped down the well bore and forced against the face of said formation under continuous and gradually increasing pressure until the pressure of said liquid against said face exceeds the breakdown pressure of said formation and causes said formation to fracture, and the said pumping is thereafter continued to force said fracturing liquid against the face of the formation and into the fractures so formed to extend the length of said fractures, the improvement which consists in applying to the top of the column of fracturing liquid in the well bore a cyclically varying pressure the amplitude and frequency of which are controlled independently of the pumping pressure, said cyclically varying pressure being applied to said fracturing liquid while continuing the pumping of said fracturing liquid against the face of said formation and said cyclically varying pressure being transmitted through the said column of liquid and applied to the said face of said formation as a cyclically varying pressure superimposed on said pumping pressure.

2. A process according to claim 1 wherein said cyclically varying pressure is applied only until the initial fracturing of the formation occurs.

3. A process according to claim 1 wherein said cyclically varying pressure is applied only subsequent to the initial fracturing of the formation and during the time when the said fracturing liquid is forced into the fractures to extend the length of the same.

4. A process according to claim 1 wherein the said cyclically varying pressure is applied prior to the initial fracturing of the formation and subsequent thereto during the time when the fracturing liquid is forced into the fractures to extend the length of the same.

5. A process according to claim 1 wherein the said cyclically varying pressure has a frequency between about 1 and about 1000 cycles per minute.

6. A process according to claim 1 wherein the said fracturing liquid is pumped down the well bore through a well tubing string, and the annulus between said tubing string and the walls of the well bore is filled with a liquid to a height substantially above the location of said formation.

7. The process for hydraulically fracturing a subterranean formation penetrated by a well bore which comprises disposing within said well bore a well tubing having its upper end extending above the earth's surface and its lower end in communication with said formation; setting at least one packer between said well tubing and the walls of the bore to isolate said formation from the rest of the bore; pumping a fracturing liquid down said well tubing and against the exposed face of said formation, said pumping being continued without interruption and at continuously increasing pressure until the pressure exerted by said liquid against the exposed face of said formation exceeds the breakdown pressure of said formation, whereby the latter is caused to fracture; continuing to pump said liquid down said well tubing and against the exposed face of said formation under sufficient pressure to force said liquid into the fractures previ-

ously formed, whereby said fractures are extended in length; and during said pumping applying to the top of the column of said liquid in said well tubing at the earth's surface a cyclically varying pressure the amplitude and frequency of which are controlled independently of said pumping pressure, whereby said cyclically varying pressure is transmitted down the column of liquid in said well tubing and is applied against the exposed face of said formation superimposed upon and in addition to said pumping pressure, the peak amplitude of said cyclically varying pressure being between about 50 and about 5000 p.s.i.g. above the said pumping pressure and the cyclic frequency being between about 5 and about 500 cycles per minute.

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Notice of Adverse Decision in Interference

In Interference No. 92,867 involving Patent No. 2,915,122, D. S. Hulse, FRACTURING PROCESS WITH SUPERIMPOSED CYCLIC PRESSURE, final judgment adverse to the patentee was rendered July 30, 1964, as to claims 1, 2, 3, 4 and 6.

[*Official Gazette May 18, 1965.*]