

July 14, 1970

E. M. GALLE

3,520,362

WELL STIMULATION METHOD

Filed Aug. 4, 1967

3 Sheets-Sheet 1

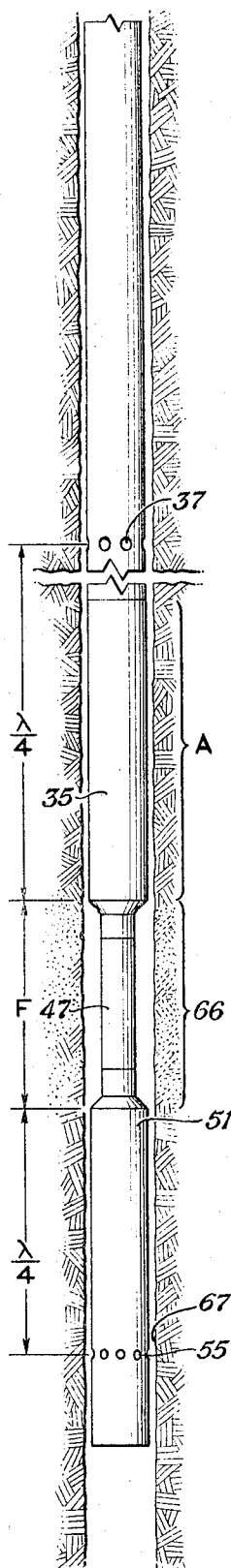


Fig. 1

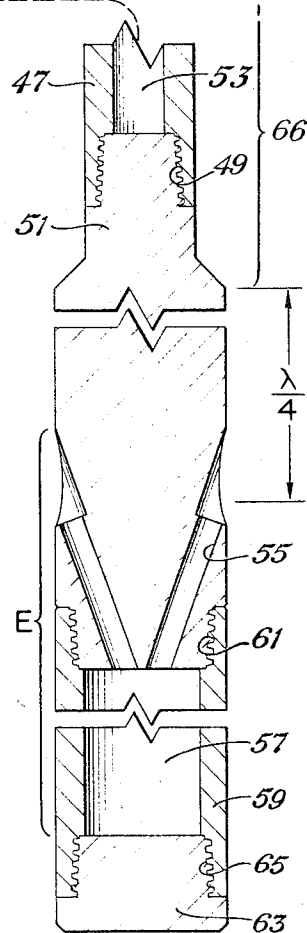
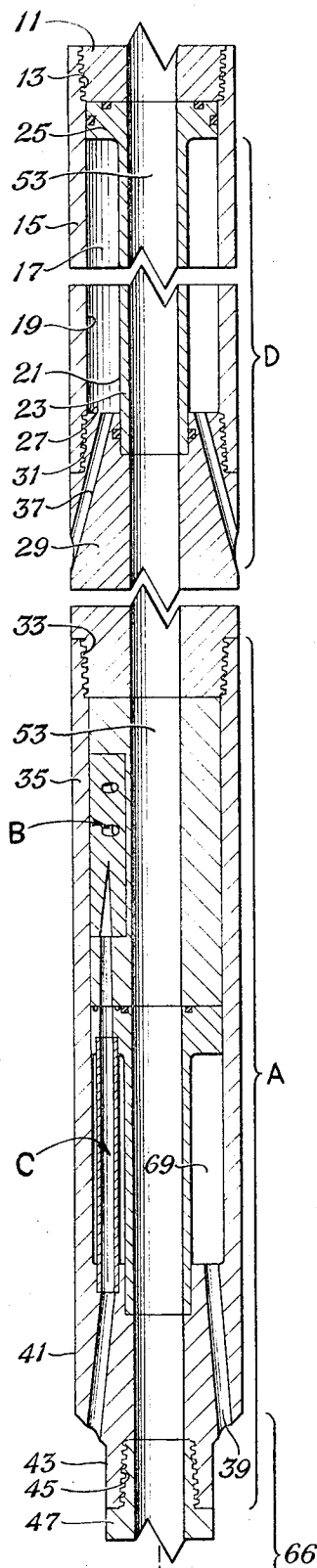


Fig. 2

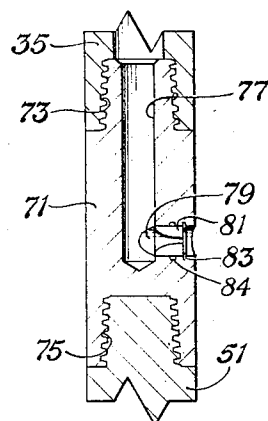


Fig. 3

INVENTOR
Edward M. Galle

BY *Wofford & Peltzman*
ATTORNEYS

July 14, 1970

E. M. GALLE

3,520,362

WELL STIMULATION METHOD

Filed Aug. 4, 1967

3 Sheets-Sheet 2

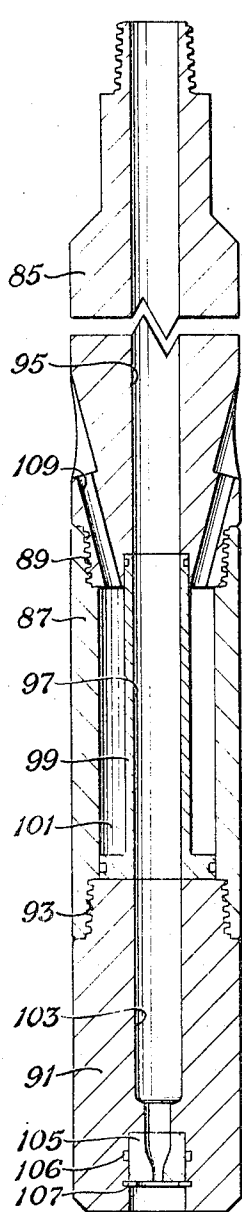


Fig. 4

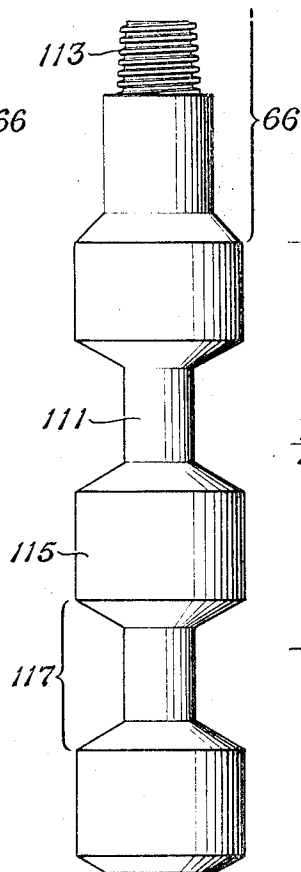


Fig. 5

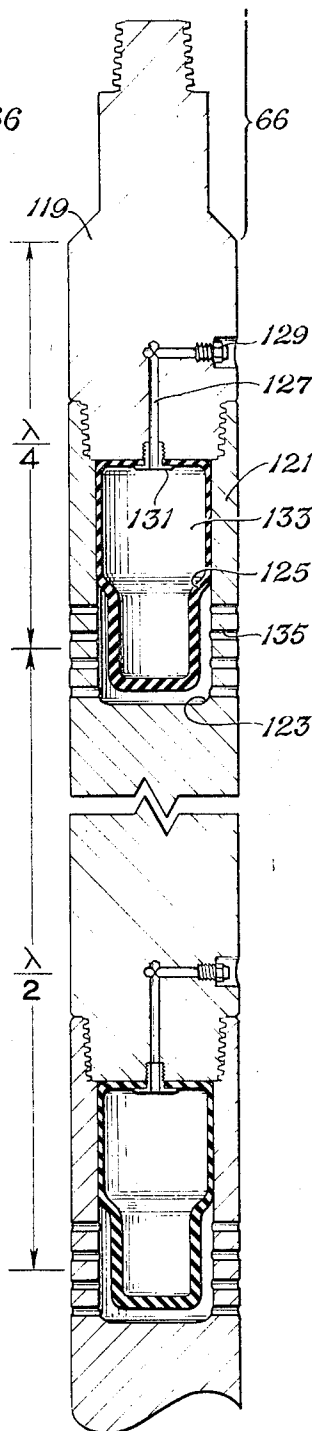


Fig. 6

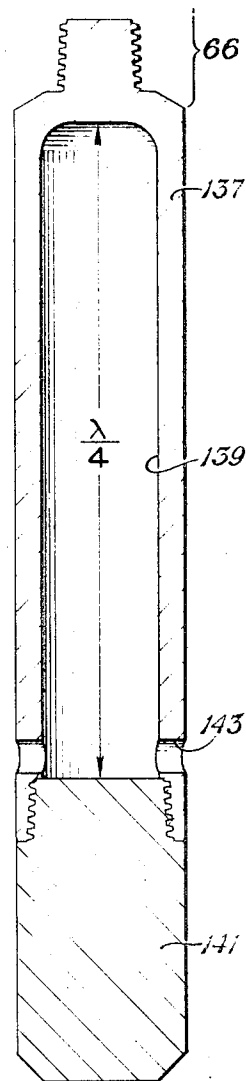


Fig. 7

INVENTOR
Edward M. Galle
BY
Wofford & Peltzman
ATTORNEYS

July 14, 1970

E. M. GALLE

3,520,362

WELL STIMULATION METHOD

Filed Aug. 4, 1967

3 Sheets-Sheet 3

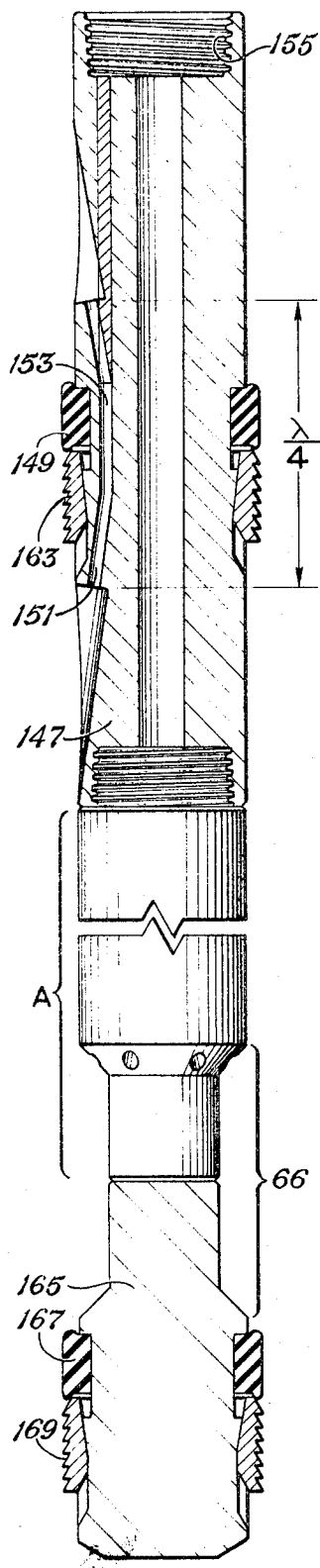


Fig. 8

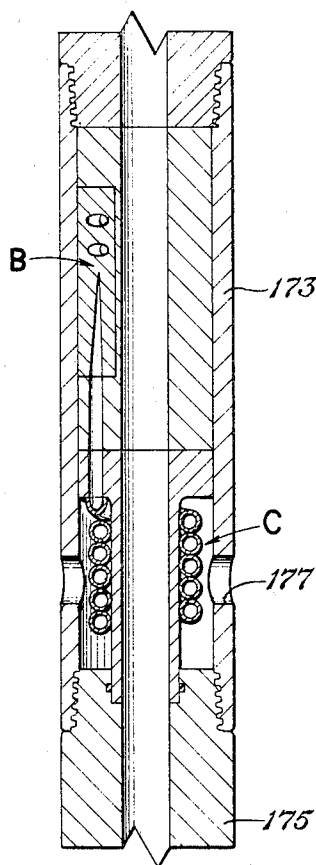


Fig. 9

INVENTOR
Edward M. Galle
BY
Wofford & Gelsman
ATTORNEYS

1

2

3,520,362

WELL STIMULATION METHOD

Edward M. Galle, Houston, Tex., assignor to Hughes

Tool Company, Houston, Tex.

Filed Aug. 4, 1967, Ser. No. 658,513

Int. Cl. E21b 43/25

U.S. Cl. 166—249

22 Claims

ABSTRACT OF THE DISCLOSURE

Following is disclosed method and apparatus for stimulating large pressure variations an isolated zone in the bore of a mineral producing well. The apparatus typically includes an oscillator unit and acoustic coupling device tuned to the operating frequency of the oscillator unit. The coupling device communicates through suitable exit ports with fluid in the region of the mineral bearing formation to be stimulated. Acoustic filters isolate the treated region from other regions in the well bore.

BACKGROUND OF THE INVENTION

Previously known techniques for stimulating mineral producing wells include acidizing, jet perforating fracturing by explosives, and fracturing with hydraulic pressure, to mention a few of the more commonly used techniques. Such techniques have been used advantageously but have a number of significant disadvantages, not the least of which result from the introduction of foreign material into the well, such as acid and sand particles. To overcome such disadvantages it has been previously suggested that acoustic energy be utilized for stimulating well production. Although this seemed feasible, commercial success did not follow, seemingly because of the practical difficulty of delivering sufficient acoustic power to the producing formation. Moreover, significant amounts of acoustical energy were dissipated throughout the fluid standing in the well bore without significant beneficial effect on the producing formation.

It is my general purpose to provide improved means of utilizing acoustic energy for efficiently stimulating mineral producing wells.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a side elevation view illustrating well stimulation means constructed in accordance with the principles of my invention; FIG. 2 is a side elevation view in longitudinal section of the apparatus shown in FIG. 1; FIG. 3 is a fragmentary side elevation view in longitudinal section of apparatus used to jet the wall of the bore hole in the region to be treated; FIG. 4 is a side elevation view in longitudinal section of a modified form of apparatus in which fluid is discharged through an outlet of selected size at the bottom of the apparatus; FIG. 5 illustrates in side elevation view an alternate form of acoustic filter which may be used with the apparatus of FIG. 1; FIGS. 6 through 9 illustrate by side elevation view in longitudinal section alternate forms of acoustic filters (sometimes called acoustic energy isolation means) used to confine acoustic energy to a selected region or zone.

DESCRIPTION OF A PREFERRED EMBODIMENT

With reference to FIG. 2 of the drawing the letter A designates an acoustic vibration generator assembly which includes an oscillator unit B and a coupling device C. The coupling device C communicates with fluid adjacent a producing region designated by the letter F in FIG. 1. An upper resonator or acoustic filter D is disposed above

the generator assembly and a lower resonator or acoustic filter E is disposed beneath the generator assembly.

Describing the above components in greater detail, beginning from the top of FIG. 2, the numeral 11 designates a threaded coupling of a tubing member, which is received by a mating threaded portion 13 of a housing 15 which contains a resonator D having a cavity 17 defined by an interior cylindrical surface 19 of the housing 15, an exterior cylindrical surface 21 of an insert 23, a flange 25 on an upper region of the insert 23, and a radial shoulder 27 on a sub 29 secured by threads 31 to housing 15 and by threads 33 to an upper portion of a housing 35 of the acoustic vibration generator assembly A. Since the insert 23 is removable in this instance, suitable seal means are used, as indicated in FIG. 2, to prevent fluid flow to or from cavity 17 except through apertures 37 extending obliquely through the sub 29. The word "tubing" is used broadly to encompass any elongated tubular member.

Housing 35 of the generator assembly A contains the acoustic coupling device C and the oscillator unit B, both of which may be of the type described in the patent application "Drilling Methods and Apparatus Employing Pressure Variations in a Drilling Fluid," Ser. No. 552,788, filed May 25, 1966. (Now U.S. Pat. No. 3,405,770, issued Oct. 15, 1968.) As described in that application the coupling device C is tuned to the operating frequency of the oscillator unit B, and has one or more exit ports 39 extending through exterior surface 41 of the housing into communication with the fluid surrounding a small diameter sub 47. The invention is not limited to the specific forms of oscillators and coupling devices described in the above mentioned application but encompasses, at least in its broadest aspects, other suitable forms of oscillator units and coupling devices, although the above fluidic (i.e., containing no moving mechanical components) devices appear to be most advantageous since they eliminate moving mechanical parts.

The lower region of the housing 35 of the generator assembly has a small diameter region 43 connected by threads 45 to a similarly small diameter sub 47 which has its lower region secured by threads 49 to the housing 51 which contains lower resonator or filter E. An axial bore 53 extends downward through the upper resonator D, sub 29, generator assembly A, and sub 47. Bore 53 terminates in this instance at the top of housing 51. However, in other embodiments this bore will communicate with passages for the flow of fluid therethrough.

In FIG. 2 one or more apertures 55 are formed obliquely in housing 51 to communicate between the annulus and a cavity 57 formed on a lower region of the housing by a sleeve 59 secured by threads 61 to the housing and by a plug 63 secured by threads 65 to the sleeve 59. The relative sizes of the apertures 55 and cavity 57 are selected such that the resonator is tuned substantially to the operating frequency of the oscillator unit B.

The volume of fluid between the wall of the bore hole and the exterior surface of sub 47 and the small diameter regions of housings 35 and 51 define an exterior acoustic tank 66 opposite the region or zone to be treated and having dimensions correlated with the dimensions of the apertures 39 and cavity 69 of the coupling device C to properly couple the oscillator unit with the acoustic load.

In operation fluid is pumped by means not shown through the axial bore 53 to feed the oscillator unit B which generates acoustic energy. This acoustic energy is transmitted by acoustic coupling device C and the exit ports 39 to the acoustic tank 66. Fluid then returns to the surface of the well bore in the annulus defined by the exterior of the apparatus and the wall 67 of the bore

hole. Consequently acoustic energy is transmitted to the fluid in the interstices in the mineral bearing formation which is illustrated in FIG. 1 as being opposite the sub 47. The distance F in FIG. 1 may be varied by inserting different lengths of subs between the housing 35 of the generator assembly A and the housing 51 of the lower resonator E to vary the length of the treated zone. Acoustic energy will normally travel both upward and downward through the well bore but is effectively prevented from doing so in this instance through utilization of the upper and lower resonators or acoustic filters D and E. Resonators D and E are used as side branches with inlets at points one quarter wave length above and below the acoustic tank 66. This effectively causes the acoustic impedance looking into the annulus from acoustical tank 66 to be very high, thus preventing any appreciable loss of acoustical power either up or down the annulus.

Very effective well stimulation may be accomplished by the use of the above described apparatus. Any type fluid may be used as motive power for the apparatus, and thus a fluid may be selected for compatibility with the formation to be treated. Only the selected regions or zone of the well need be affected by the stimulation process. Both the length of the treated zone and the depth of treatment into the producing formation may be controlled through the use of proper fluid properties and frequencies of operation. In addition, the use of large pressure variations for well stimulation may be used in conjunction with or simultaneous with hydraulic fracturing techniques. It is not necessary to use mechanical packers to accomplish the stimulation operation; thus stimulation in open holes may be accomplished without side wall damage.

Best results may be obtained by utilizing pressure variations having frequencies in the range from 25 to 5000 cycles per second. The amplitude of the pressure variations required for effective stimulation depends upon the formation to be stimulated; however good results may be expected with pressure variations ranging from 250 p.s.i. peak to peak to 3000 p.s.i. peak to peak. Lower frequencies of operation are best when stimulation is required in the mineral bearing formation a considerable distance from the well bore while the higher frequencies of operation are best when it is necessary to treat shallow distances into the producing formation. In addition, the length of the apparatus is affected by the selected frequency. The apparatus for low frequencies is in general rather long while the apparatus for high frequencies may be quite short. A wave length may be calculated by dividing the velocity of wave propagation in the drilling fluid in the annulus in feet per second by the frequency of operation in cycles per second. From the calculated wave length, the length of the required apparatus may be determined.

Apparatus of the type described above and as shown in the drawing may be used to stimulate the production from mineral bearing earth formations by a combination of cleaning, fracturing, and enlargement of the formation pores or interstices. Such apparatus has a high degree of efficiency due to the prevention of excessive energy loss upward or downward through the fluid in the bore hole.

In some instances it seems desirable to jet the wall of the bore hole in the treated zone while simultaneously stimulating the treated zone with acoustic energy. In FIG. 3 is illustrated a sub 71 having a threaded upper portion 73 and a threaded lower portion 75 which may be secured respectively to the housing 35 and the housing 51 of FIG. 2. An internal bore 77 communicates with a radial bore 79 which in this instance receives jet nozzle 81 which may be retained by a snap ring 83 and sealed with an O-ring 84. Fluid pumped from the surface of the well is discharged from the nozzle 81 against the wall of the bore hole. By rotating the apparatus and altering its elevation, fluid may be discharged against a substantial area of the bore hole wall in the treated zone. This

technique may be especially advantageous in removing foreign particles from the wall of open bore holes to enable more effective penetration of acoustic energy into the producing formation. The nozzle 81 or its equivalent may be oriented to discharge fluid horizontally or obliquely; and possibly it is best to discharge the fluid upward in the direction of fluid flow returning in the annulus to the surface.

A number of forms of the apparatus may be used for isolating the acoustic energy to a selected zone other than the acoustic filters shown in FIGS. 1 and 2. One such alternate form of apparatus is illustrated in FIG. 4 where the numeral 85 designates the body of a lower acoustic filter having a sleeve 87 secured by threads 89 to its lower region. A terminal section 91 is secured by threads 93 to the sleeve 87 and an axial passage 95 extends through body 85, communicating with a bore 97 in an insert 99 forming an annular cavity 101 between sleeve 87 and insert 99. Terminal section 91 has a bore 103 which communicates with a nozzle 105 sealed by O-ring 106 and secured by snap ring 107 to discharge fluid from the bottom of the apparatus. Moreover, body 85 has one or more oblique apertures 109 (the entrances of which are spaced one quarter wave length or an odd multiple thereof below acoustic tank 66) which communicate between the annulus and the cavity 101. Suitable seal means are provided between the insert 99 and the remainder of the apparatus to confine fluid flow through the apertures 109. Cavity 101 and passages 109 constitute a Helmholtz resonator tuned to the operating frequency of the oscillator unit, which receives only a portion of the fluid flow, the remainder passing through a selected size nozzle 105 to enable washing of the bore hole wall along the entire length of the treated zone.

FIG. 5 illustrates another form of acoustic filter adapted in this instance for utilization in defining the lower extremity of an isolated zone. This filter has a cylindrical body 111 having its upper end 113 threaded for securement to the remainder of the apparatus and further having a plurality of enlarged regions 115 that form inertance sections with the wall of the well. Consequently, one or more external fluid cavities 117 are formed along the length of the body. This structure forms a series of inertance sections and expansion chambers which isolate the treated zone from the remainder of the bore hole. For additional information on this type filter see for example the second edition of "The Fundamentals of Acoustics," by Kinsler and Frey, John Wiley, Inc. publishers, New York, N.Y., 1962, p. 209.

Another form of acoustic filter is illustrated in FIG. 6. In this apparatus an upper body region 119 is adapted for engagement with a lower body region 121, which has a cavity 123 that receives a flexible, fluid impervious membrane 125 filled with gas under pressure introduced through a suitable aperture 127 and connection 129. A metal fastener 131 may be bonded to an upper portion of the membrane for threaded securement to the body 119 and for convenient communication of the membrane interior cavity 133 with aperture 127. Cavity 123 is larger than the membrane 125 when unexpanded. When lowered in the bore hole, the pressure of the gas confined by the membrane's cavity 133 and the fluid pressure communicating with the membrane through apertures 135 in the body 121 become equalized such that the membrane may assume the shape illustrated in FIG. 6. The plurality of apertures 135 and high pressure gas in cavity 133 form a low acoustic impedance side branch to the quarter wave length transmission line (formed by the annulus between the exterior of body 119 and the bore hole) which results in a high acoustic impedance looking down the annulus from tank 66. If necessary, more than one such acoustic filter may be used to further reduce power loss, and if so, it is disposed a half wave length from the first filter as indicated in FIG. 6.

5

In FIG. 7 is illustrated another form of acoustic filter in which a body 137 having an internal cavity 139 which terminates on its lower end with a plug 141. Cavity 139 is fed by very large apertures 143 and is a quarter wave length long or an odd multiple thereof. Moreover, the distance from the upper shoulder 145 to the apertures 143 is one quarter wave length or an odd multiple thereof. The impedance looking into apertures 143 is very low, and forms a side branch to the quarter wave length transmission line formed by the bore hole and the exterior of body 137 as indicated in FIG. 7. The impedance looking downward into the annulus from the acoustic tank 66 is, on the other hand, very high.

Another form of acoustic energy isolating means is illustrated in FIG. 8, the principal distinguishing characteristic of this apparatus being that it utilizes mechanical (as contrasted with the previously described acoustic) isolator elements that may be referred to as packers. The acoustic vibration generator assembly A has disposed on its upper end a packer body 147 having a resilient packer element 149 which may be expanded into engagement with the wall of the bore hole or casing 67 of FIG. 1. In instances where fluid is to be pumped through the annulus to the surface of the well, a quarter wave length passage 151 is formed in the body 147, bypassing packer 149. The upper end of the passage 151 is formed obliquely in this instance to intersect a straight portion 153 plugged above their intersection as shown. Threads 155 are provided for securing body 147 to the tubing string (not shown). Conventional packer gripper elements 163 which may be operable in one of the conventional manners engage the casing, or perhaps rigid bore hole wall, to urge upward and outward the resilient packer element 149. A lower packer is secured to lower portion of the acoustic vibrator assembly A having a body 165 and a resilient packer element 167 which is expanded when the gripper elements 169 engage the wall of the bore hole. The lower packer element 167 is spaced as close as practicable to the external acoustic tank 66. The upper packer element 149 is preferably placed as close as practicable to the top of the acoustic tank 66 but in this embodiment, owing to the space limitations created by the internal components inside the acoustic vibrator assembly A, the upper packer element is placed one half wave length from the top of the acoustic tank 66. In either instance acoustic vibrations are prevented from travelling up or down the bore hole past the packer elements while enabling DC flow through passage 151. If DC flow is not wanted up the annulus past the packer element 149, as might possibly occur when using acoustic energy in combination with conventional fracturing with hydraulic pressure, tube 151 may be plugged, thus enabling the packer element 149 to function both as a DC and AC flow block.

In FIG. 9 is illustrated apparatus which does not include the use of an external acoustic tank. The housing 173 contains an oscillator unit B and a coupling device C of the type shown in FIG. 9 of the above mentioned patent application. Here however a terminal portion 175 prevents fluid flow from the lower end of the coupling device C, and one or more large apertures 177 extend radially through housing 173 is approximately the mid-region of the coupling device and preferably in the mid-region of the mineral bearing region to be treated. Acoustic isolator elements such as Helmholtz resonators are spaced one quarter wave length or an odd multiple thereof above and below the apertures 177.

My invention is not limited to the specific forms of apparatus shown since there are a variety of oscillator units, acoustic coupling devices and resonators which fall within the scope of my broad concept. Therefore, while I have shown my invention in only a few of its forms it should be apparent to those skilled in the art that it is not so limited but is susceptible to various changes and modifications without departing from the spirit thereof. The primary method disclosed above utilizes the energy in the

6

fluid flowing down a drill string to generate acoustic vibrations which are transmitted into the annulus in the vicinity of a mineral bearing formation. The acoustic energy in the annulus is confined to a selected zone or region through utilization of isolator elements which may be of the type described above. An additional method employs utilization of DC flow through a suitable flow restriction means, such as a nozzle, for jetting the wall of the bore hole in the treated region to remove foreign matter such as filter cake, thus increasing the penetration and effectiveness of the acoustic stimulation. An additional method comprises the utilization of DC flow blocks that isolate the AC flow to the selected zone while simultaneously enabling large fluid pressure build-up in the selected zone. This enables the use of conventional hydraulic fracturing techniques concurrently with isolated acoustic vibrations. Modifications to the above methods which come within the broad scope of my invention will become apparent to those skilled in the art.

I claim:

1. A well stimulation method comprising the steps of: pumping a circulating fluid down a well bore through a tubing string; converting a portion of the energy of said circulating fluid into acoustic vibrations; transmitting said acoustic vibrations to the fluid adjacent the region to be stimulated; isolating the acoustic vibrations to said region; and returning said circulating fluid to the surface through an annular space external of said tubing string.
2. The well stimulation method defined in claim 1 wherein the frequency of acoustic vibration ranges from substantially 25 to 5,000 cycles per second.
3. The well stimulation method defined by claim 1 wherein the peak-to-peak amplitude of the pressure variations range from substantially 250 to 3000 p.s.i.
4. The method defined by claim 1 which further comprises the step of jetting the bore hole wall in the region to be treated with fluid discharged from the tubing string.
5. The well stimulation method defined in claim 1 wherein said isolating is acoustical.
6. The well stimulation method defined in claim 5 wherein the frequency of acoustic vibration ranges from substantially 25 to 5,000 cycles per second.
7. The well stimulation method defined by claim 5 wherein the peak-to-peak amplitude of the pressure variations range from substantially 250 to 3000 p.s.i.
8. The well stimulation method defined in claim 1 wherein the said isolating is effected with a Helmholtz resonator disposed an odd multiple of a quarter wave length from the region to be stimulated.
9. The well stimulation method defined in claim 8 wherein the frequency of acoustic vibration ranges from substantially 25 to 5,000 cycles per second.
10. The well stimulation method defined by claim 8 wherein the peak-to-peak amplitude of the pressure variations range from substantially 250 to 3000 p.s.i.
11. A well stimulation method comprising the steps of: pumping a circulating fluid down a tubing string; converting a portion of the energy of said circulating fluid into acoustic vibrations by means of a fluidic vibration generator; transmitting said acoustic vibrations from the fluidic vibration generator to the fluid adjacent the region to be stimulated; and acoustically isolating the acoustic vibrations to said region.
12. The well stimulation method defined in claim 11 wherein the frequency of acoustic vibration ranges from substantially 25 to 5,000 cycles per second.
13. The well stimulation method defined by claim 11 wherein the peak-to-peak amplitude of the pressure variations range from substantially 250 to 3000 p.s.i.
14. The method defined by claim 11 which further comprises the step of jetting the bore hole wall in the

region to be treated with fluid discharged from the tubing string.

15. The well stimulation method defined in claim 11 wherein the said isolating is effected with a Helmholtz resonator disposed an odd multiple of a quarter wave length from the region to be stimulated.

16. The well stimulation method defined in claim 15 wherein the frequency of acoustic vibration ranges from substantially 25 to 5,000 cycles per second.

17. The well stimulation method defined by claim 15 wherein the peak-to-peak amplitude of the pressure variations range from substantially 250 to 3000 p.s.i.

18. The well stimulation method defined by claim 11 wherein the said acoustic vibrations are generated with a bistable fluidic oscillator having 2 output legs with the vibrations in one leg being phase inverted before transmission to the fluid adjacent the region to be stimulated.

19. The well stimulation method defined by claim 18 wherein said phase inversion is effected by means of an inertance-compliance network.

20. The well stimulation method defined by claim 18 wherein the said phase inversion is effected by means of a half wave length delay line.

21. A well stimulation method comprising the steps of: pumping a fluid downwardly through a tubing string and subsequently into the annulus of a well bore in the region to be stimulated;

fluidically generating with a portion of the energy of said circulating fluid acoustic vibrations in the vicinity of the formation to be treated;

transmitting said acoustic vibrations from the vibration

generator to the fluid in the annulus adjacent the region to be stimulated; and

blocking fluid flow upward or downward in the annulus to increase the fluid pressure and hydraulically fracture the mineral producing formation and simultaneously isolating the acoustic vibrations of said region.

22. The method defined by claim 21 which further comprises the step of jetting the bore hole wall in the region to be treated with fluid discharged from the tubing string.

References Cited

UNITED STATES PATENTS

Re. 23,381	6/1951	Bodine	166—43
2,680,485	6/1954	Bodine	166—45 X
2,700,422	1/1955	Bodine	166—177 X
2,824,718	2/1958	Currie	175—56
2,871,943	2/1959	Bodine	166—42
2,915,122	12/1959	Hulse	166—42
3,045,749	7/1962	Brandon	166—42
3,163,240	12/1964	Bodine	175—56
3,378,075	4/1968	Bodine	166—45
2,805,044	9/1957	Giles	175—56
2,816,612	12/1957	Hutchison et al.	166—177
2,951,682	9/1960	Boucher	175—56
3,323,592	6/1967	Brandon	166—42
3,415,330	12/1968	Bouyoucos	175—46

DAVID H. BROWN, Primary Examiner

U.S. Cl. X.R.

166—177, 305