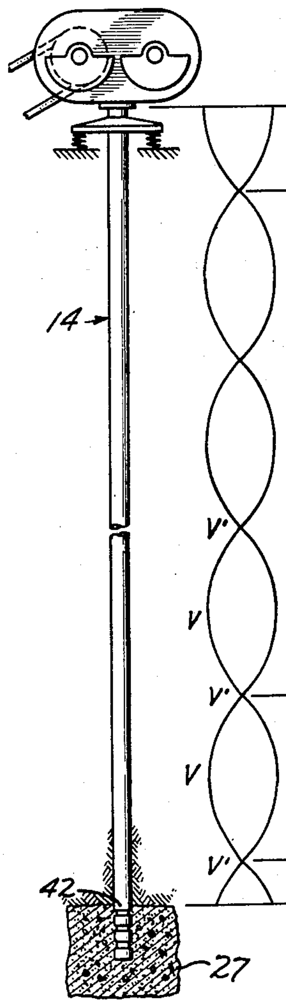



Fig. 2.

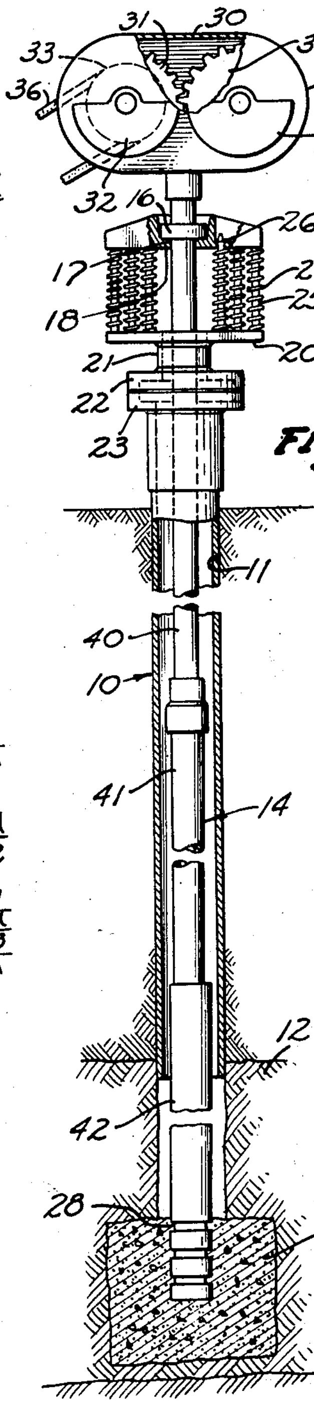
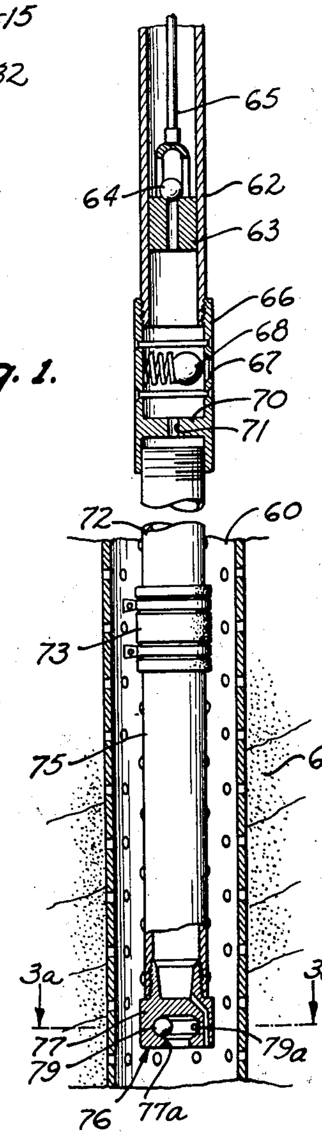



Fig. 1.

Fig. 3.

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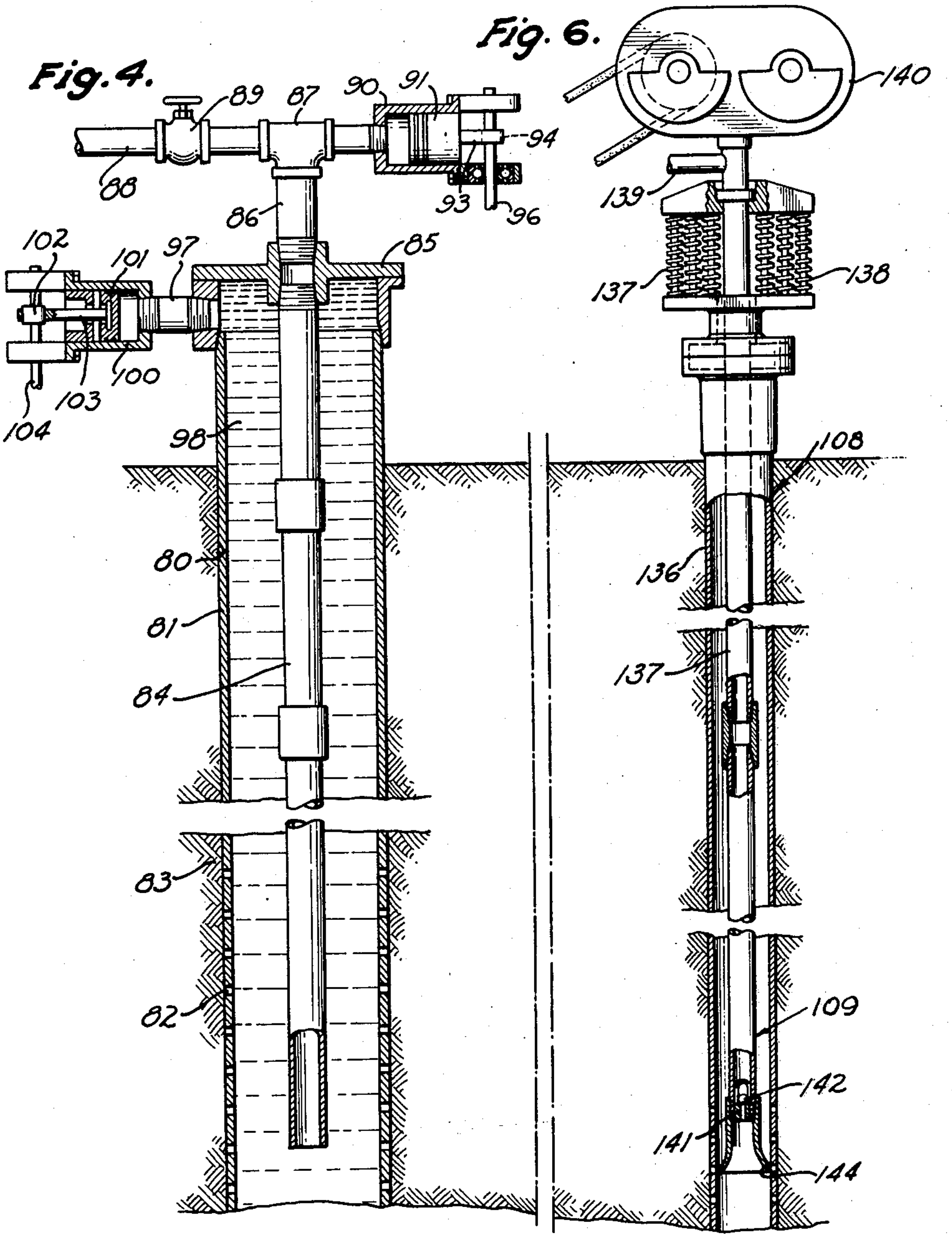


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Jan. 25, 1955 A. G. BODINE, JR 2,700,422

SONIC SYSTEM FOR AUGMENTING THE EXTRACTION OF PETROLEUM FROM PETROLEUM BEARING STRATA

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Fig. 7.

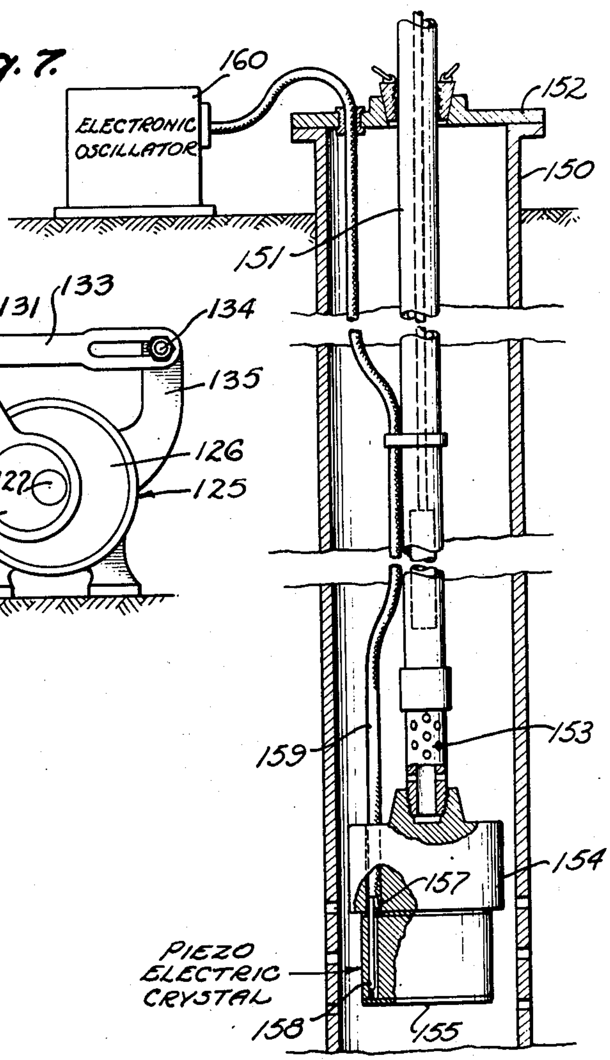



Fig. 5.

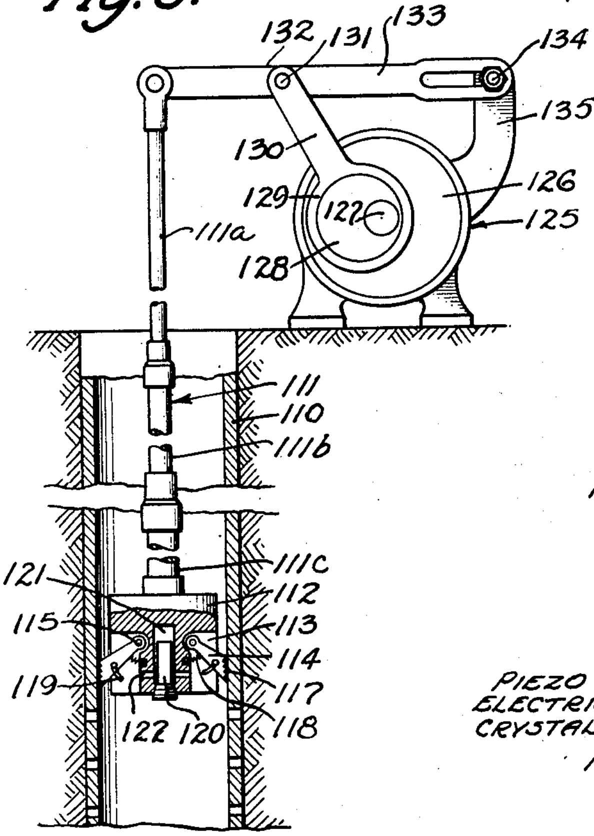
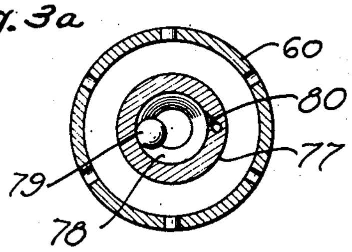



Fig. 3a

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2,700,422

# SONIC SYSTEM FOR AUGMENTING THE EXTRACTION OF PETROLEUM FROM PETROLEUM BEARING STRATA

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Original application February 17, 1948, Serial No. 8,799. Divided and this application August 24, 1950, Serial No. 181,308

3 Claims. (Cl. 166—9)

This invention relates generally to systems for increasing the flow of petroleum wells, and deals generally with the system for increasing the flow from the petroleum bearing strata to the well by application to the strata of elastic waves of sonic character, i. e., waves travelling in the strata with the speed of sound. The present application is a division of my prior application filed February 17, 1948, Serial No. 8,799, now Patent No. 2,667,932 for Sonic System for Augmenting the Extraction of Oil From Oil Bearing Strata, which prior application was copending with and a continuation-in-part of my parent application which eventuated in Patent Number 2,437,456, filed May 14, 1941, and issued March 9, 1948.

My said prior Patent 2,437,456 taught the concepts of transmitting sound waves through an oil bearing formation to augment the flow of oil therethrough to a producing well, the heating of the formation or the oil therein by the effect of sound wave transmission, the transmission of sound wave impulses from a well through the surrounding formation to surrounding productive wells, so as to increase the flow of fluids through the formation to the surrounding wells, and the pumping of a washing fluid down a pump tubing and out into the formation in conjunction with the generation of sound waves or sound wave vibrations impressed upon the downwardly pumped wash fluid stream, and therefore upon the surrounding formation. This subject matter, thus disclosed in said prior patent, and continuation-in-part application Serial No. 8,799 copending with the application which eventuated in said patent, is the claimed subject matter of the present divisional and continuation-in-part application.

As disclosed in my said prior patent and prior application, the rate of migration of oil through wet sandstone can be increased very materially by transmitting sound waves through the standstone. By sound or sonic waves, I refer to waves of elastic deformation propagated in the formation with the speed of sound, and not necessarily waves limited to the frequency range of human hearing ability. My invention contemplates the utilization of the elastic deformation movement of the formation in response to sound waves for the accomplishment of a flow of petroleum fluid through the porous oil bearing earthen formation to an adjoining oil well. It is beyond the scope of this invention to theorize all of the reasons why the invention is effective. However, the following factors are apparent:

Sound waves travelling in an elastic medium are subject to attenuation, the lost energy of the wave being converted into heat. Heat generates gas pressure, as well as reducing the viscosity of the oil, and hence oil migration must be increased.

Oil is trapped in earthen formations by gas bubbles and water "filaments" bridging the gaps between sand particles. Periodic acceleration of the formation by transmitting sound waves therethrough causes or permits the oil droplets to puncture these bubbles and filaments, and so to become freed for migration.

Oil exhibits boundary layer adhesion to the surfaces of the sandstone, which seriously impedes the flow of the oil to the well, but which can be materially reduced by transmitting sound waves through the sandstone, the oil or both. Such waves act to reduce the frictional drag of the formation on the well fluid by agitating, breaking up and scrubbing away the boundary layers of the fluid which are otherwise bound adhesively to the formation.

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Whether or not the above factors are exhaustive of the flow promoting conditions established by the invention, is a question beyond present knowledge. Suffice it to say at this time that I have found sound waves applied to an oil bearing earthen formation to materially augment the flow rate therethrough.

The improvements of the present invention contemplate the transmission of sound waves from the region immediately adjacent one well to regions adjacent other wells, and thus to augment the flow rate from a group of wells in the formation, though using but a single well as a source of waves. Further, I may employ an abandoned well as a source of sound waves by installing high power sound wave generating apparatus therein, with no revived production from that particular well attempted. The high energy waves transmitted to the formation from the high power apparatus thus installed are propagated for a considerable distance through the formation, and may thus revive wells over a substantial field area. The invention further contemplates the pumping of wash fluids down one well of a group of wells, such injected fluids coacting with the flow-inducing effects of sonic wave transmission through the formation by washing the petroleum fluids toward the surrounding producing wells.

Various additional objects and features of the invention will be made apparent in the course of the following detailed description, reference being had to the accompanying drawings, in which:

Figure 1 is a longitudinal sectional view, partly in elevation, showing one type of means for generating the elastic sound waves in the oil bearing formation;

Figure 2 is a somewhat diagrammatic view showing a simplified form of apparatus and showing also a desirable standing wave pattern;

Figure 3 is a view partly in longitudinal section and partly in elevation showing another form of apparatus for generating sonic waves in the formation, the apparatus being this time installed in connection with a producing pumping apparatus;

Figure 3*a* is a transverse section on line 3*a*—3*a* of Figure 3;

Figure 4 is a longitudinal sectional view, partly in elevation, showing an oil well installation in accordance with the invention designed to pump wash fluids down the well and into the formation;

Figure 5 is a view, partly in longitudinal section and partly in elevation, showing another embodiment of apparatus for generating sound waves in the formation;

Figure 6 is a view, partly in longitudinal section and partly in elevation, showing a sonic pump which may be used for production purposes and at the same time for generating sonic waves in the formation; and

Figure 7 is another view in longitudinal section and partly in elevation showing another form of apparatus for generating the desired sonic waves in the formation.

The purpose of the present invention, in one general aspect, involves and depends upon several important steps, viz.: generating high energy sound waves, efficiently transmitting said waves to the productive formation, effecting an efficient energy transfer between the transmission means and the formation, injecting of wash fluids or liquids into the formation by way of a downwardly pumping well installation, and suitable productive pumping means installed in connection with one or more productive wells. Several distinct forms of apparatus for creating the sound waves in the formation are disclosed herein, and the process invention may most conveniently be understood from a consideration of these several forms of apparatus which may be used in connection with the water injection and production pumping steps of the invention.

Referring first to Figures 1 and 2, an apparatus for generating sound waves is shown to be installed in an abandoned oil well (or earth bore not to be used as a producing well). Numeral **10** designates well casing sunk in bore **11** to the region of oil productive stratum **12**. Such casings may originally have extended to the bottom of the bore, but for present purposes is preferably cut off near the top of the oil-bearing stratum 12, as indicated.

An elastic column 14, composed of a good grade of elastic steel, is suspended within casing 10, and has mounted on its upper end sound wave generator 15, one embodiment of which is to be described in more particular hereinafter. Near the upper end of column 14, the column is furnished with an enlarged head or collar 16. The column 14 fits in an aperture 17 formed in a horizontal top plate 18, the head 16 overhanging and bearing downwardly on said plate around aperture 17 for the support of the column. Vertically spaced below top plate 18 is a horizontal bottom or base plate 20 carried by tubular member 21 and flange 22 bolted to casing head flange 23. Between base plate 20 and top plate 18 are a plurality of coil springs 24, positioned on vertical pins 25 set tightly into base plate 20 and projecting with working clearance through bores 26 in top plate 18. The weight of the column 14 is thus transferred to springs 25, and thence to the casing 10 supported by the earth.

A body of cement 27 is filled in the well bore around the lower portion of the column. If desired, the column may be grooved as at 28 to key the column to the cement body and thus assure vibrating movement of the latter with the column. Alternatively, a body of packed wet sand may be used in place of the cement. This body of cement or sand, as the case may be, places the elastic column in solid-to-solid engagement with the formation, thus providing good wave energy transmission between the column and the surrounding formation, as more fully described hereinafter.

Sound wave generator 15 comprises a housing 30 containing a means for setting up vertically directed vibrations and thereby exerting a vertical oscillating force upon the upper end of the column 14. The means for generating these vibrations may be mechanical, electrical, hydraulic or any other type capable of delivering sufficient power. A type of generator well adapted for the purpose has meshing oppositely rotating gears 31 carrying eccentric weights 32 which balance out horizontal vibrations but cause vertical vibrations to be additive to produce a substantial resonant oscillatory force in a vertical direction. The driving pulley 33 of the sound wave generator, mounted on the shaft for one of the spur gears, is driven by an electric motor or any other suitable prime mover (not shown) through belt 36.

In a simplified embodiment of the invention, the column 14 may consist of a steel column of substantially uniform diameter from the generator 15 to its lower end. Such an embodiment is somewhat diagrammatically represented in Figure 2, together with a typical standing wave pattern therefor. For simplicity, the operation of the apparatus of Figure 1 will first be described with the assumption that the column 14 is actually of uniform diameter from top to bottom.

Generator 15 applies an oscillating force in a vertical direction to the upper end of elastic column 14, thereby launching alternating elastic deformation waves of tension and compression in a longitudinal direction down the column, said waves travelling in the elastic column with the speed of sound. The transmission of elastic waves along the length of an elastic column is a well understood phenomenon usually treated of in works on acoustics under the heading of "longitudinal vibrations of rods" and need not be explained in great detail herein. It should, however, be understood that longitudinal elastic waves in an elastic column cause sections of the rod to oscillate longitudinally of the column, with a displacement amplitude depending upon the energy of the wave and the longitudinal stiffness of the column.

The column 14 is usually long relative to a wave length measured along the column. Waves in the approximate frequency range of 10 to 30 cycles per second appear to give the desired high amplitude waves capable of travelling long distances in the formation, e. g., hundreds of feet. A 20 cycle wave has a wave length in the column of the order of 800 feet, and the column may hence be several wave lengths (fundamental frequency) long for a typical oil well installation. Various harmonics, of lesser wave lengths, may also appear.

It will of course be clear that the wave frequency is determined by the speed of the sound wave generator 15, and that by varying the speed of the latter, all or any of the desired ranges of frequencies may be employed. The vibration amplitude of the generator will of course depend upon its frequency, and it is found that a moderately low sonic frequency, as 10 to 30 cycles, affords the necessary vibration amplitude for equipment of the type herein disclosed.

For efficient transmission of the wave energy from the generator down the elastic column, the generator should be adjusted to a resonant frequency of the column, so as to establish a standing wave along the column, as represented in Figure 2, this being accomplished in the case of a column with "free" ends, by adjusting the speed of the generator to produce such a wave length along the column that the column length is equal to an even number of quarter wave lengths. The standing wave results from interference of waves reflected by the ends of the column with the generated wave, as is well understood in the art of acoustics. In an actual installation the lower end is not entirely "free" because it is reactively connected to the formation so that the latter becomes part of the resonant circuit. Nevertheless, good reflections of waves occur at the lower end. The conventional standing wave diagram to the right of the column in Figure 2 represents the envelope of vibration amplitude at various sections along the column, assuming moderate reactance at the lower end, and it will be observed that the upper end and lower end sections of the column, as well as sections spaced by a half-wave from the column ends, experience substantially maximum vibration amplitude, while sections midway therebetween experience zero or minimum amplitude. The terms "velocity and anti-node" and "velocity node" are conventionally applied to the maximum and zero amplitude regions of the standing wave, as indicated at V and V′, respectively, in Figure 2. Such resonant standing wave conditions assure optimum power transmission from the generator down the column to the body of cement 27, and thence to the formation.

The use of a vibration generator 15 characterized by simple harmonic motion is of substantial importance, since such a generator generates sound waves permitting the application of acoustic methods to accomplish good energy transfer between the steel column and the formation. Good coupling and good energy transfer to the earthen foundation is desired especially in the more powerful forms of my invention, such as those employing steel columns, because large amounts of energy can be transmitted without over-stressing the steel if the energy is rapidly transmitted from the bottom to prevent excessive resonant amplitude. Such energy transfer depends upon the provision of a good impedance match between the column and the formation, which is accomplished by the use of a column having heavy mass and large area in contact with the formation, or with the cement body, which is in turn a heavy body of large surface in contact with the formation. In the case of a filled-in body of packed sand, such body is very tightly packed under the high pressure involved, and becomes, in effect, a part of the formation. A determination of the weight of the bottom end portion of the column in engagement with the formation is also governed by the frictional resistance to its reciprocation and by the resistance to its movement offered by the material in contact therewith, or with the cement body in which it is embedded. The bottom end column portion (section 42 of Figure 1) must be made of sufficient weight that its efficiency as an energy transmitting member is not overcome by the inertia and other resistance to motion of its environment, which, if the column is very light, may serve to damp out entirely its movement and render negligible the wave energy transmitted thereby.

In operation, elastic waves generated at the top of the column are transmitted down the column as periodic alternating waves of tension and compression, the waves preferably being generated at a resonant frequency of the column, all as already explained. These waves set the lower end portion of the column into vertical oscillation, from which the wave energy is transmitted to the cement body 27, and thence to the surrounding earth formation in which the cement body is embedded. The wave energy so delivered to the elastic earth formation travels radially outward in the latter with the speed of sound. These elastic waves travelling in the oil bearing stratum 12 are reflected at the boundaries thereof by reason of the substantial difference in impedance usually encountered in two adjacent strata. With high energy waves of steep wave front such as may be transferred to the earth formation with the apparatus of Figure 1, the wave action is effective for hundreds of feet to augment the flow rate through the earthen formation by reason of heating, removal or reduction of the adhesive boundary layer on the surfaces within the interstices of the formation, and removal or puncture of internal flow-impeding water filaments in the formation.

The specific elastic column **14** of Figure 1 is made up of several sections **40**, **41** and **42** of increasing cross-sectional area and massiveness in a downward direction, the bottom section **42** being for example 7½" in diameter, and about 110′ long. The increasing cross-section causes an increase in longitudinal dynamic stiffness, which results in turn in reduced amplitude of vertical oscillation. The reduction in amplitude of oscillation, however, is accompanied by a corresponding increase in the force with which the column moves. The "tapered" column thus functions as an acoustic lever, transforming the wave energy delivered by the generator to a higher impedance state characterized by reduced amplitude of travel and correspondingly increased force. This higher impedance wave energy in the massive lower end section **42** of the column is appropriate for the high impedance load (the earthen formation) which the elastic column must drive. It should also be noted that the increased mass and surface of the lower section **42** of the column is also of advantage from another standpoint, in that the coupling between the column and the formation is thereby improved. Increased energy transfer from the column to the formation is thus accomplished.

If there be employed as a prime mover for driving the generator **15** a gas engine, or a non-synchronous electric motor, it will be found that the engine or motor will automatically assume a speed establishing one of the modes of resonant operation of the wave train in the column. Approaching resonance, any increase in speed of the prime mover automatically considerably increases the amplitude of oscillation, thus increasing the energy load on the prime mover, so that the prime mover "runs up against the load," or in other words, holds that speed corresponding to the maximum torque it is adjusted to develop. If for any reason the prime mover should tend to slow down, the wave amplitude would appreciably decrease, thereby considerably reducing the load, whereby the prime mover would at once regain its lost speed. Increase in speed without increasing the energy input into the prime mover is prevented by the substantial increase in load that automatically follows any increase in speed. The system operated in this manner is thus automatically governing.

Figure 3 shows a form of the invention in which the sonic generator of elastic waves is installed in connection with a well pump and is operated simultaneously with the pump. In this form of the invention, therefore, the wave generator not only augments flow to surrounding wells, but particularly to the same well in which it is situated. In Figure 3, number **60** designates the usual perforated casing embedded in productive formation **61**. Pump tubing **62** has mounted therein the usual plunger **63** carrying travelling valve **64** and adapted to be reciprocated by sucker rod string **65**. The drawing shows only the lower portion of the well, the well pump equipment above and at the ground surface being understood as entirely conventional. Pump tubing **62** has screwed onto its lower end a tubular body **66** having a laterally opening intake port **67** controlled by standing valve **68** urged against its seat by spring **69**. Below valve **68** is a wall **70** pierced by a small fluid port **71**, which may discharge fluid downwardly from the pump tubing into a pipe section **72**. To the lower end of the latter is coupled, as by flexible coupling **73**, a gyratory elastic tube or pipe section **75**, which in the present instance carries at its lower end a fluid driven wave generator **76**. The latter comprises a head **77** coupled to the lower end of pipe section **75** and furnished with an internal annular groove forming a race **78** for a gyratory ball **79**, the latter being driven by a tangential fluid jet discharged from tangential nozzle **79*a*** communicating as indicated with the lower end of pipe section **75**. The lower end of body **77** has a fluid discharge port **77*a***.

In operation, the column pressure in the pump tubing is imposed on the fluid in nozzle **79*a*** during each down stroke of the pump plunger **63**, and fluid is accordingly discharged from nozzle **79*a*** to drive ball **79** in a circular path at relative high velocity. This rotating ball exerts a centrifugal force against the lower end of the elastic pipe **75**, causing the latter to be continuously subjected to a rotating force vector in a transverse plane which force vector is designed to be of sufficient magnitude to bend or deflect the lower end of the pipe in a circular path in a transverse plane. This circular bending deflection of the elastic pipe **75** is propagated the length of the pipe, so that each section thereof participates in the gyratory action. The nozzle may be designed to drive the ball, under the column pressure available, at any desired speed, usually in the range of 10 to 100 revolutions per second. Preferably, the frequency of rotation of the ball is made to correspond substantially with the fundamental resonant frequency of the pipe **75**, which results in resonating the pipe and establishing a standing wave therealong, the latter being characterized by velocity nodes (points of minimum transverse deformation) located at one quarter of its length from each end, and velocity anti-nodes (points of maximum transverse deformation) at its center and at both ends. This standing wave is the result of elastic waves of transverse deformation propagated longitudinally up pipe **75** and reflected from its upper end, the transmitted and reflected wave interfering in such a way at the resonant frequency as to give the nodes and anti-nodes as described.

It should now be noted that the gyratory deformation of each section of the pipe may be analyzed to be the resultant of two transverse vibrations occurring in directions at right angles to one another, and with 90° phase difference between them. The generator thus combines the effect and power of two uni-directional vibrators operating in quadrature on direction lines at right angles to one another, and is therefore, in fact, a harmonic vibration generator. It is of course within the scope of the invention to substitute a generator which oscillates or vibrates in but one direction.

The action of the pipe **75**, whether gyratory (oscillation along two direction lines in quadrature phase) or oscillatory (to and fro) along a single direction line, results in transmission of elastic wave energy to and radially outward through the immediately surrounding medium, which is the well fluid in the casing. The sound waves in the well fluid are thus transmitted to the casing, and out through the casing perforations (which may desirably, in some cases, be enlarged to augment the wave transmission) into the surrounding oil bearing formation. The sound waves arriving at the casing walls set the casing into vibration and the casing in turn transmits the sound waves into the oil bearing formation. The sound waves thus transmitted into the formation augment the oil flow rate through the formation and from the formation to the well, as already described.

In other embodiments of my invention, I may locate the sonic wave generator entirely at the ground surface and utilize a well fluid column as a wave transmission path to the oil bearing formation. Such a system is disclosed in Figure 4. An essential feature of the invention claimed in the present application is the pumping of wash fluids down one of the wells of a group of wells, such wash liquid being intended to coact with sonic waves or sonic vibrations set up in the formation in promoting the flow of petroleum fluids towards the producing wells of the group. This can be accomplished through various forms of well installation, but I have selected the apparatus of Figure 4 to illustrate the fluid injection feature of the invention.

In Figure 4, numeral **80** designates the well bore, **81** the casing, perforated as at **82** opposite the oil bearing formation **83**, and **84** the flow tubing suspended inside casing **81**. The upper end of tubing **84** is screwed into casing head **85**, the flow being received above head **85** by nipple **86** screwed into the stem of T **87**. To one arm of T **87** is screwed pipe line **88** containing valve **89** and to the other arm is coupled cylinder **90** containing piston **91** reciprocated by eccentric **94** and connecting rod **93**, the eccentric being driven by rotating shaft **96** powered by any suitable prime mover, not shown.

Figure 4 also shows a pipe **97** coupled at one end to casing head **85**, so as to communicate with the annular well fluid space **98** between the casing and the tubing **84**. The other end of this pipe **97** is coupled to cylinder **100** containing piston **101** reciprocated by eccentric **102** and connecting rod **103**, the eccentric being driven by shaft **104**, powered by any suitable prime mover, not shown.

Operation of the apparatus of Figure 4 is as follows: The wash water or other fluid is pumped into pipe **88**, down tubing **84** and finally into the formation, using any type of suitable surface pump, not necessary here to illustrate. The reciprocating piston **91**, operated at sonic frequency, impresses sonic impulses upon the descending column of wash fluid, which impulses travel down the descending fluid column in the tube **84** with the speed of sound, the sonic impulses being finally radiated into the formation with the effect of increasing the flow rate of the petroleum fluids therethrough. It is also possible to transmit sonic waves into the formation by utilizing the piston **101** and fluid column between casing **81** and tubing **84** in connection with the pumping of wash fluid down the tubing **84**. The piston **101** is in this case driven at the desired sonic frequency, and piston **91** may be inactive. This second or alternative possibility of the apparatus of Figure 4 suggests that the transmission of sound wave energy to the formation need not necessarily be by way of sound waves impressed on the descending wash fluid column, but may follow any suitable transmission path from the wave generator to the formation. Thus any wave generator means and wave transmission path may be employed, such as some of those disclosed in other figures of the present application. The two Figures 4 and 6 taken together illustrate one complete system in accordance with the invention for sending wash fluid down one well, sending sound wave energy into the formation, and recovering resulting augmented production from an adjacent well containing a production pump. Thus, for this purpose, the well **108** of Figure 6, containing pump **109**, may be regarded as any suitable pump placed in the same field or formation with the wash fluid pumping apparatus of Figure 4, so as to benefit by the augmented production possibilities created by the sound wave transmission and wash water injection created by operation of the apparatus of Figure 4. The pump utilized as the producing pump can be of any suitable deep well type, though I have shown a particular type of sonic pump which will be described in more particular hereinafter. It is only necessary here to refer to the fact that petroleum fluids in the formation between the wash fluid pump and the production pump will be driven to flow toward the latter both by the sonic wave or vibrational energy impressed on the formation by the column of wash fluid, and also by the wash fluid itself. The effect of the sonic vibrational energy on the petroleum fluids in the formation is again the product of several factors, viz., heating, puncture of water filaments, destruction of boundary layer conditions, and probably also alternate expansion and contraction of the formation caused by the passage of the sound waves.

Forms of my invention wherein the sound wave energy is transmitted by a fluid column, for instance those represented by Figure 4, are greatly aided in their ability to transmit power by maintaining a high mean pressure on the fluid, "mean pressure" being the static pressure level above and below which the fluid pressure alternately rises and falls with passage of the sound wave. It is thus desirable, for the transmission of large amounts of power, that the mean pressure be as high above atmospheric as practicable. Because of the hydrostatic head of the column, the mean pressure in the lower regions of the well will be exceedingly high. A mean pressure above atmospheric can be imposed on the fluid column in the well in the case of a flowing well by closing down somewhat on the valve **89**, thus imposing a back pressure on the fluid column. Closing this valve of course tends to reduce the flow rate, but in some cases the overall effect will be to increase the flow rate by transmitting stronger sound waves into the formation. The pressure on the fluid column in the case of pumping wash fluid down the tubing **84** is of course under the control of the pump supplying the wash fluid, and can be increased by increasing the delivery pressure of the pump.

Additional power transmission down a fluid column is also gained by resonating the column. For instance, the piston **91** can be operated at a resonant frequency of the pipe **84**, creating a standing wave in the fluid column, as well understood in the science of acoustics. A similar result can be obtained by operation of the piston **100** at a resonant frequency of the fluid column between the casing **81** and tubing **84**.

In Figure 5 is illustrated an embodiment of my invention in which sound wave impulses are transmitted to the oil bearing formation through a well casing **110**, the pumping equipment having been removed. The figure in this case, for simplicity, omits a showing of the well bore and casing above the lower region of the well, since those parts are conventional, but the vibration generator at the ground surface is shown, together with an upper end portion of the elastic vibration transmitting column. In this embodiment there is secured to the lower end of an elastic column **111**, which preferably may be a string of elastic sucker rod sections **111*a*, 111*b*,** and **111*c*** of progressively increasing cross-section in a downward direction, a massive body **112**. Milled into the sides and bottom of this body are slots **113** in which are received anchor shoes **114** pivotally mounted on pins **115** set into the body **112**. The shoes **114**, shown in expanded position in the full lines of the drawing, are provided with casing engaging serrations **117** adapted to engage and grip the casing, the shoes being moved to expanded position by coil springs **118** placed between the shoes and the body, as indicated. In the expanded, casing gripping position, the anchor shoes extend angularly downward and outward from their pivot mountings on the body so that the weight of the body **112** and column **111**, or a portion thereof, if imposed on the expanded shoes in engagement with the casing, will cause the serrations to bite into the casing.

The shoes **114** may be retained in retracted position during installation in any suitable manner. For instance, they may be initially secured down against expansive springs **118** by a shear wire **119** adapted to be sheared by a small weight **120** movable in a central body cavity **121** through which the wire **119** is caused to pass by way of apertures **122**. Transmission of vibratory energy down the column **111** in the manner presently to be described will vibrate the weight **120** against the wire **119** and cause it to fatigue and break, whereupon the anchor shoes are expanded by the springs and grip the casing.

The weight of the body **112** together with a portion of the weight of the column **110** is permitted to be assumed by the casing, causing an elastic deformation of the casing in a downward direction. Of course the casing will part if too heavily loaded, so care must be exercised that only enough loading be transferred to the casing to give it the desired elastic deformation.

A sonic frequency vibration generator **125** at the ground surface is operatively connected to the upper end of the elastic column **111**. This generator **125** in this instance comprises an electric motor **126** whose shaft **127** operates an eccentric **128** in the strap **129** of a connecting rod **130**. The rod **130** is pivotally connected at **131** to an intermediate point **132** of a lever **133**, one end of which has a pivotal mounting **134** on frame bracket **135** of motor **126**, and the other end of which is pivotally connected to the upper end of column **111**. It will be seen that rotation of motor **126** will result in connecting rod **130** being driven to oscillate lever **133**, and thereby reciprocate the upper end of column **111** through a short vertical displacement distance. This movement of the upper end of column launches alternating elastic waves of compression and tension down the column, causing the lower end portion thereof, and the body **112**, to oscillate vertically at the frequency of the generator **125**. This oscillation is transmitted via shoes **114** to the casing, causing the whole lower end region of the latter to participate in the oscillation. The casing acts as a spring supporting part of the load of body **112**, thus oscillating locally in unison therewith. It must be understood that in all ordinary situations the column **111** will not be bodily reciprocated, the wave lengths of the waves transmitted in the column being much shorter than the column length. In accordance with well known principles of elastic vibrations in rods, different portions of the column may be moving in opposite directions owing to the progress of the wave action down the column.

Preferably, to assure maximum power transmission down the column, the wave generator **125** is operated at a resonant frequency of the column, so as to establish a standing wave therealong, which may be generally similar to that diagrammed in Figure 2, having a velocity antinode at the top, a velocity anti-node at the bottom (where the engagement is made with the casing), and a number of half-wave spaced velocity anti-nodes between. The mass of the body **112** at the lower end of the column **111** will have a reduced amplitude of oscillation because of the increased longitudinal dynamic stiffness of the column sections **111**_b_ and **111**_c_, and also because of its own ample acoustic impedance, but this reduction is accompanied by a desirable increase in force such as is necessary to oscillate the casing and to transmit substantial wave energy to the formation outside.

As already partially described, the suspension of the column from the lever **133** is so adjusted that a portion of the column weight along with the weight of the body **112** will be transferred to the casing, thus imposing a net "bias" on the casing causing an elastic deformation thereof. If the wave amplitude of cyclic displacement of the body **112** as driven by the column **111** is less than the supporting bias deformation of the casing the latter will oscillate in step with the body **112**. The elastic wave energy is transmitted from the casing to and into the formation by direct contact therewith.

In Figure 6, numeral **136** designates the perforated casing in the well bore, and **137** an elastic steel pump tubing suspended therein from coil type springs **138**, the upper end of said tubing delivering well fluid to pipe **139**. A sonic wave vibration generator **140**, like the generator of Figure 1 is mounted on the top end of the tubing.

A check valve seat ring **141** is tightly mounted in the tubing, near the lower end thereof, and is provided with check valve ball **142**, while the lower end of the tubing is flared out laterally, nearly to the diameter of the casing, as indicated at **144**.

In operation, generator **140** transmits elastic waves of tension and compression down the pump tubing, causing the lower end portion thereof (including not only the flare **144** but the ring **141**) to be longitudinally reciprocated through a short displacement distance at the frequency of operation of the generator **140**. This action, and the preferred establishment of resonance in the tubing, are fully discussed in my application Serial No. 761,456, now Patent No. 2,444,912. Each down stroke of seat ring **141** with the tubing occurs at an acceleration greater than gravity, and the check valve ball accordingly unseats during such time. Fluid displaced by the downwardly travelling seat ring therefore flows up through said ring and fills the void above the ring caused by the down stroke of the latter. On the upstroke of the ring, the check valve ball seats, and the column of fluid thereabove is elevated.

The flared lower end of the vertically oscillating pump tubing, working with relatively close fit within the casing, functions as a piston in the casing to reciprocate a substantial column of well fluid, and hence furnishes a good wave transmission coupling to the fluid. Sound waves are accordingly set up in the fluid, and are radiated to and through the casing and into the surrounding oil bearing formation.

Figure 7 shows diagrammatically an embodiment of my invention employing a higher frequency device for generation of the waves radiated into the formation. The casing is here indicated at **150**, a line of production tubing at **151**, and a casing head, supporting the tubing **151**, at **152**. Tubing **151** has a perforated strainer **153** connected to its lower end, and to the lower end of strainer **153** is connected a weight **154**, on the bottom of which, in turn, is mounted piezo-electric crystal **155**. The upper and lower sides of crystal **155** are electroplated to provide electrically conductive surfaces, and to these are connected the ends of two conductors **157** and **158** led down in a cable **159** from electronic power oscillator **160** at the ground surface. The crystal may have a supersonic resonant frequency of 100,000 C. P. S., and the oscillator is designed to furnish it with electric current of that frequency, causing it to vibrate at the said resonant frequency. The upper side of the crystal being backed up by the high impedance mass **154**, the lower side thereof



will transmit vibratory energy to the fluid in the well, to be radiated out to, through and past the casing into the oil bearing formation.

The crystal **155** is, of course, of small area in comparison with the cross-sectional area of the casing, and if its frequency were of the low order considered in the earlier described embodiments, its coupling efficiency with the well fluid would be very poor, and it would not function to radiate elastic waves into the formation. However, at the high frequency range mentioned, wave lengths in the liquid across the bottom of the crystal become short in comparison with the dimensions of the crystal, and the crystal then becomes an elastic wave radiator, capable of efficient transmission of wave energy into the surrounding media. This phenomenon occurs when a half-wave length of the wave generated in the medium is no greater than the dimension across the crystal.

As is well known, the directional property of a wave train increases as the frequency increases or the wave length decreases. It will be seen, therefore, that because of this tendency of impulses in the liquid generated by the crystal vibrator to travel in the direction of travel of the crystal, the amount of clearance between the crystal and the casing may be increased as the frequency of vibration is increased (or the wave length of the wave train in the liquid is decreased). For frequencies below approximately 100 vibrations per second, the vibrator should fit rather closely within the casing, as it does, for example, in Figure 6.

Various illustrative embodments of my invention have now been described. It is of course to be understood that these are not to be regarded as the only forms which the invention can take in practice, and that the invention is to be limited only in accordance with the language of the following claims.

I claim:

1. The process for increasing the recovery of petroleum from an oil bearing formation which comprises: coupling a sonic wave generator to the oil bearing formation, operating said generator to transmit sonic waves through said formation, simultaneously forcing a driving liquid through the oil bearing formation, and producing oil from the formation.

2. A process for the production of petroleum which comprises coupling a plurality of wave generators to an oil-bearing formation, connecting each wave generator to a separate power source so that each wave generator is driven at a frequency which is determined by the frequency of its power source whereby the formation is vibrated with a wave having an energy content determined by the combination of the vibrations from the wave generators, forcing a driving liquid through said oil-bearing formation simultaneously with said vibrating, and producing oil from said oil-bearing formation.

3. The method of claim 2 wherein one of said generators is coupled to said formation adjacent an input well for said driving liquid and another of said generators is connected to said formation adjacent an output well for said produced oil.


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