

March 2, 1954

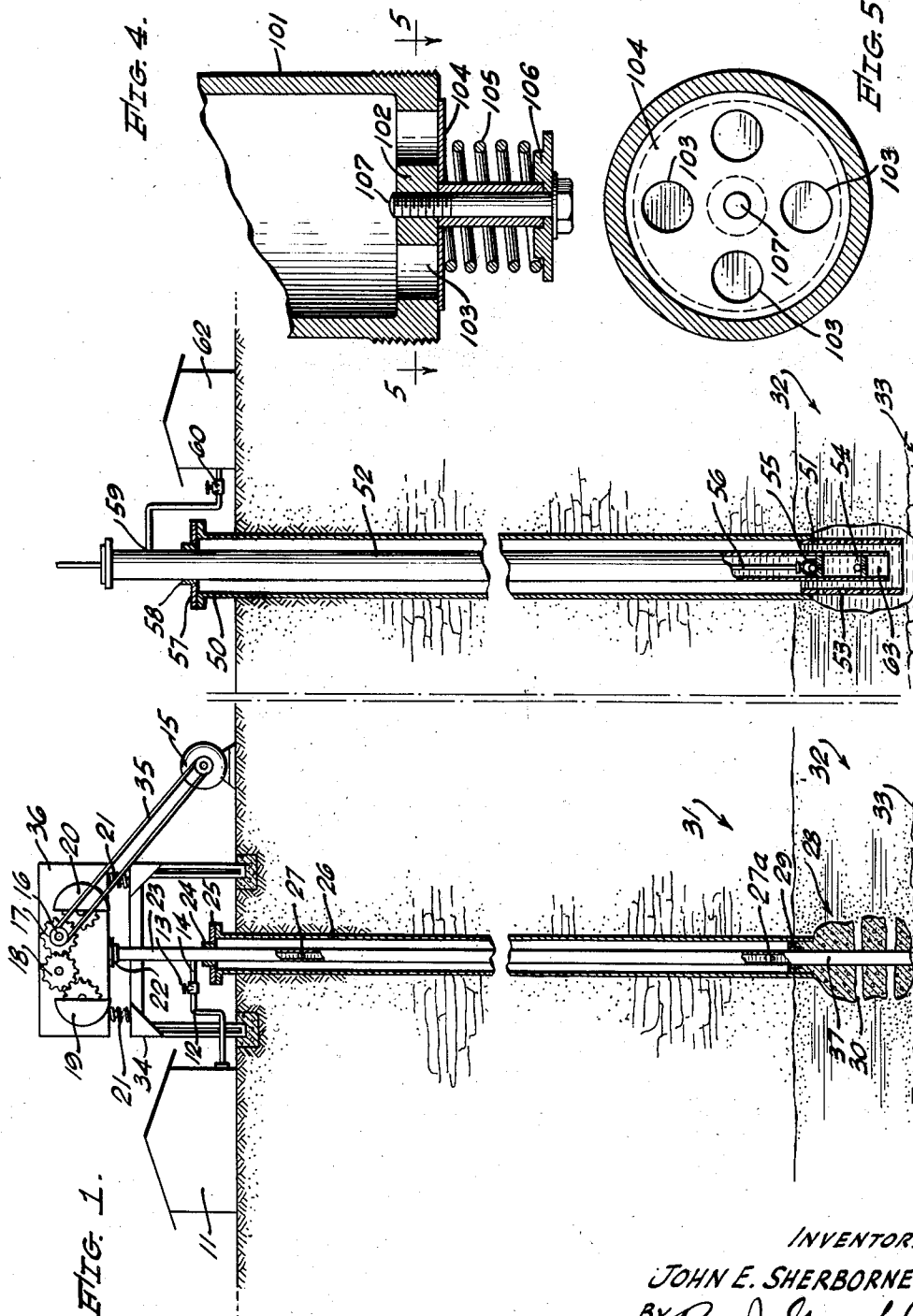
J. E. SHERBORNE

2,670,801

RECOVERY OF HYDROCARBONS

Filed Aug. 13, 1948

4 Sheets-Sheet 1



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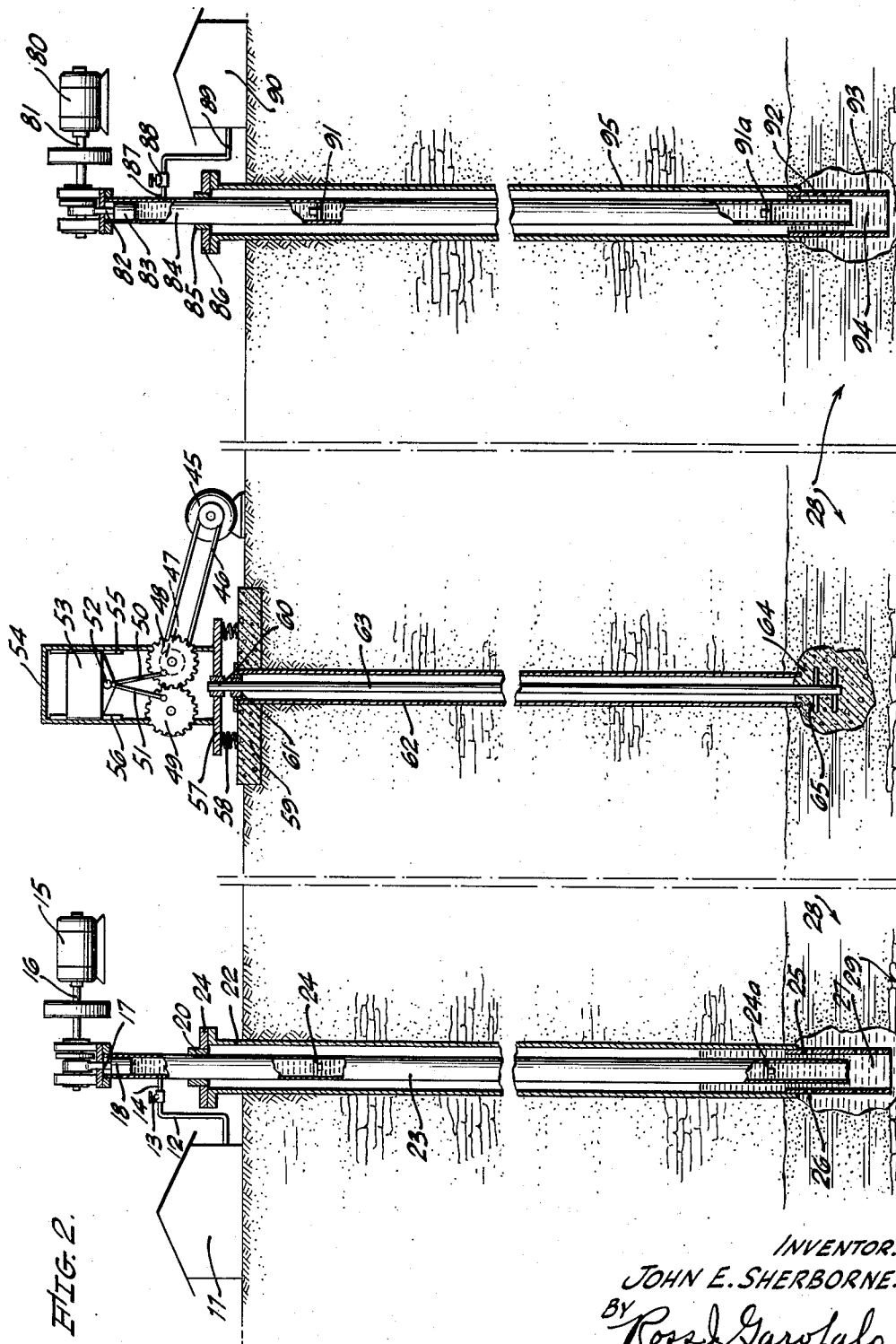
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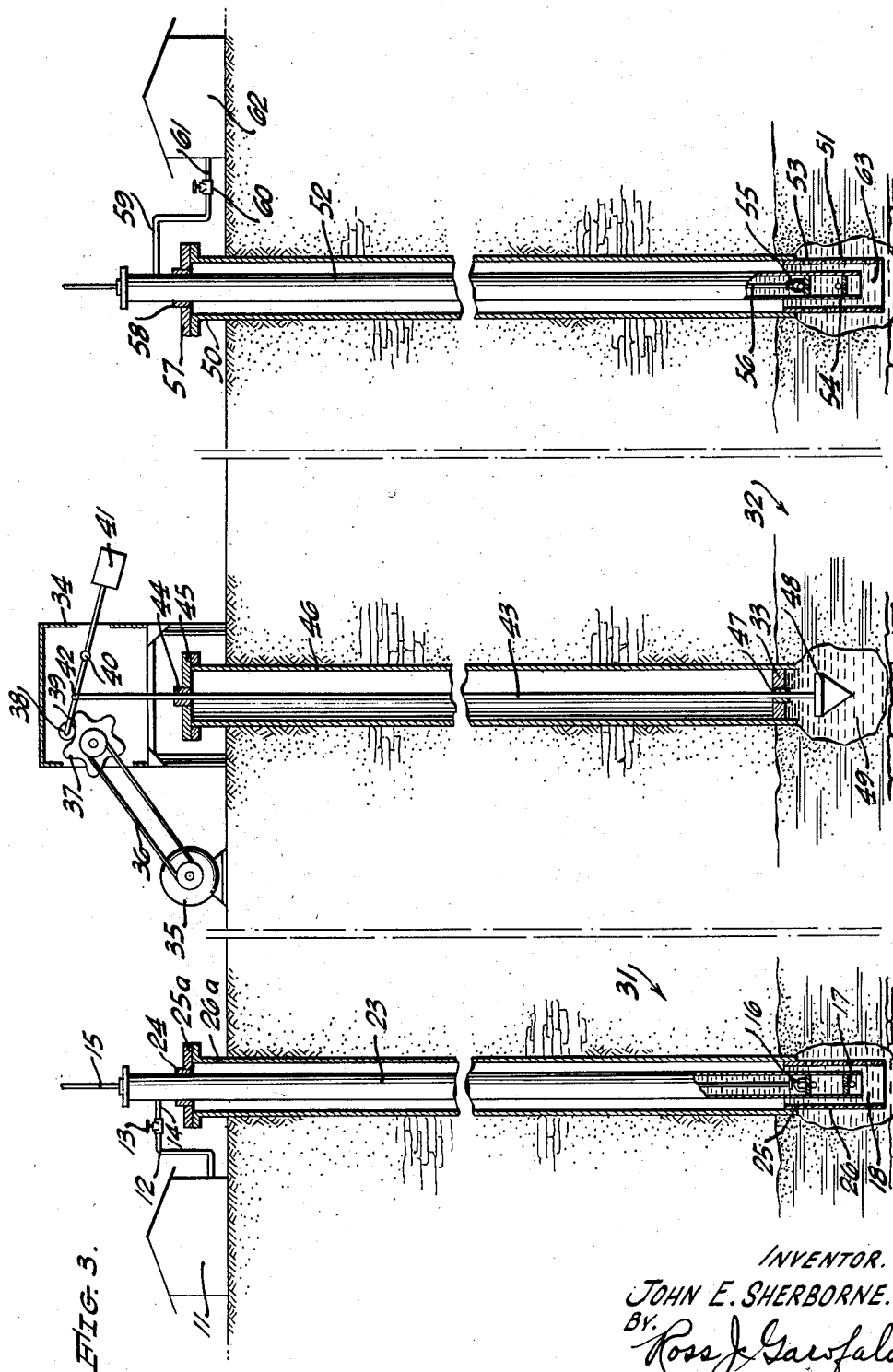
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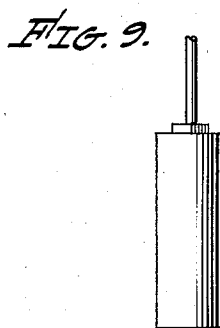
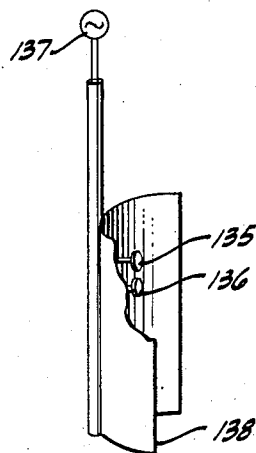
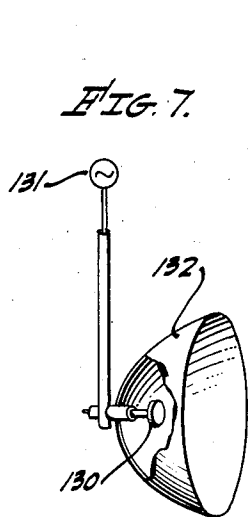
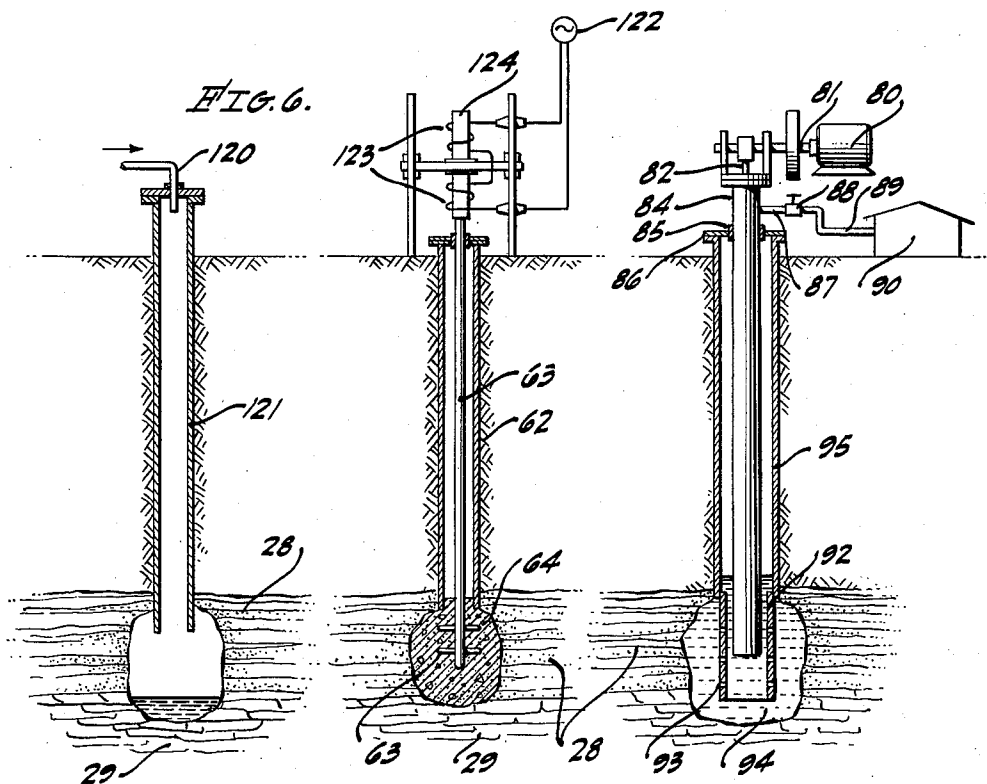


FIG. 8

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RECOVERY OF HYDROCARBONS

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8 Claims. (Cl. 166—21)

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This invention relates to the use of sonic or supersonic waves for increasing the recovery and production of crude petroleum from oil-bearing formations. More particularly, this invention relates to use of sonic and ultrasonic or supersonic vibrations in conjunction with secondary recovery processes employing fluid drive, such as water flooding, gas drive and the like, whereby the efficiency of the driving liquid or gas for stripping oil from the oil-bearing formation is markedly improved by the employment of such vibrations.

As the age of an oil field increases the formation pressure finally decreases to a point where there is insufficient potential energy in the formation to cause the oil to flow to production wells at commercially significant rates. As producing wells approach this state, it has been the practice to force a driving agent or driving fluid such as water, oil field brine, natural gas, flue gas, air or the like into the oil-bearing formation from an input well centrally located with respect to several producing wells for the purpose of driving oil into the latter. The use of driving agents has not been confined solely to wells which are approaching depletion however. More recent developments in oil production include the water flooding and gas driving of virgin fields whereby the net production of oil by the flooding, or the driving, of the virgin field is greater than that which would be obtained by the separate operations of producing the well to near depletion and subsequently flooding or driving the field in the normal way.

Most oil-bearing formations are considered to be sands which consist of pores or channels of widely varying textures and degrees of permeability. During flooding or driving operations water, gas or the like is forced into the oil-bearing formation under sufficient pressure to wash or push a part of the oil remaining in the formation toward and ultimately into the producing well or wells.

The flooding or driving operation is of limited value for effecting secondary recovery and increasing the net yield of oil from a formation because of the fact that the water or gas preferentially strips the oil from the most permeable channels initially and then continues to flow at steadily increasing rates through the partially oil-free channels of high permeability. This condition is further accentuated by the lower viscosity of water or gas as compared to that of most oils. The channeled flow of flooding liquid or driving gas progressively increases the water

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to oil ratio, or the gas to oil ratio, at the production well or wells until the point is reached at which it becomes economically unsound to continue the flooding or driving operation, and the wells must be abandoned even though the oil content of the formation is far from exhausted. A number of procedures are practiced in the art to improve the yield of oil by secondary recovery such as for example, the selective plugging of the more permeable strata, but such methods have thus far proved to be of minor value.

It has now been found that sonic or supersonic vibrations when impressed upon an oil-bearing formation provide a method for markedly increasing the efficiency of a fluid or gas drive process. The vibration of the oil-bearing formation supplements the energy supplied by liquid flooding or gas driving processes thereby increasing the net yield of oil over that which would be obtained by the usual liquid flooding or gas driving processes. The formation can also be vibrated prior to the flooding or gas driving operation in order to dislodge a part of the oil from the less permeable areas thereby placing it in a condition to be more easily removed by the subsequent flooding or driving operations. Alternatively, the formation undergoing secondary recovery can be either heated or simultaneously heated and vibrated by employing high frequency waves, or complex waves derived from both low and high frequency vibrations.

A primary object of this invention is to stimulate oil production prior to and/or during the liquid flooding or gas driving of oil-bearing formations by means of sonic or supersonic mechanical vibrations.

It is another object of this invention to agitate and/or heat oil-bearing formations undergoing secondary recovery by the application of high and/or low frequency vibrational energy to the formation.

Another object of this invention is to reduce undesirable channeling of the driving agent through the oil-bearing formation during a secondary recovery operation through the use of mechanical vibrations.

Another object of this invention is to increase the ratio of oil to water obtained from the production wells during the flooding of oil fields.

It is another object of this invention to employ sonic and/or supersonic pumps for introducing the driving liquid into an oil-bearing formation from an input well during a secondary recovery operation and/or for removing the

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oil from the oil-bearing formation at an output well, which sonic and/or supersonic pumps simultaneously impart vibrational energy to the liquid being pumped, a part of which energy is in turn imparted to the oil-bearing formation undergoing secondary recovery and thereby increasing the yield of oil.

Briefly, this invention relates to the liquid flooding or gas driving of oil within an oil-bearing formation wherein sonic or supersonic mechanical vibrations are impressed upon the oil-bearing formation prior to and/or during the operation to enhance its efficiency. The essential elements for carrying out this invention include a means for supplying the driving fluid under sufficient pressure to force it into the oil-bearing formation, one or more sonic or supersonic wave generators, a transducer and transducing medium to couple the vibration generating system to the oil-bearing formation to be vibrated and a pumping system for removing the oil from the oil-bearing formation at a point away from the introduction of the driving fluid. The driving fluid may be any suitable gas or liquid.

The means for supplying the driving fluid to the oil-bearing formation include centrifugal pumps, reciprocating pumps, sonic pumps, compressors and the like. The sonic or supersonic wave generator may be any mechanically or electrically driven wave generator capable of introducing large amounts of mechanical vibrational energy into the oil-bearing formation. Suitable generators may be purely mechanical types such as any of those which are described hereinafter, piezo-electric crystals coupled with low or high frequency oscillating electrical currents, magneto-strictive devices and the like. The transducer and transducing medium comprises any suitable arrangement for coupling the mechanical vibrations generated by the wave generator to the oil-bearing formation. The transducing medium is preferably solid or liquid. Under certain limited conditions such as those which prevail in high pressure formations gaseous media may be employed. However, gases tend to absorb the mechanical vibrations thereby decreasing the intensity of the transmitted wave. In the specific case where a driving fluid is a liquid which is introduced into the oil-bearing formation by means of a sonic pump, the driving liquid itself may function as the coupling between the sonic vibrating generator and the formation to be vibrated. In other cases the transducer may comprise a solid metallic rod fastened to the wave generator and coupled to the oil-bearing formation through a large block of cement, concrete, plastic, melted or solidified alloys, various liquids, or other material lodged within or in the vicinity of the oil-bearing formation. In any case oil is removed from the oil-bearing formation at an output well by conventional reciprocating oil pumps, by sonic pumps or by any other suitable means.

Figure 1 shows one modification of the invention wherein a sonic pump is employed to introduce the driving liquid into the formation and to impart vibrational energy to the formation simultaneously. The stripped oil is removed from the formation by means of a conventional pump.

Figure 2 shows another modification of this invention wherein sonic pumps are employed to introduce the driving liquid and to remove the stripped oil and wherein a wave generator is coupled to the formation to supply additional vibration energy to the formation.

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Figure 3 shows another modification of this invention wherein conventional pumps are employed to introduce the driving liquid into the formation and to remove the stripped oil and wherein a wave generator is coupled to the formation to supply vibrational energy thereto.

Figure 4 shows one modification of a sonic check valve which is spring loaded from the underside to cause downward fluid flow in a sonic pumped injection well. For upward fluid flow such as in a sonic pumped output well the check valve shown in Figure 4 is merely inverted and mounted in the pump tubing.

Figure 5 shows a section taken along the line 5-5 of Figure 4.

Figure 6 shows a modification of the invention shown in Figure 2 wherein a conventional gas drive apparatus injects a gas into the formation and wherein a wave generator of the magneto-strictive type is coupled to the formation to supply additional vibrational energy to the formation; as in Figure 2 the oil is removed from the formation by means of a sonic pump. Apparatus common to Figures 2 and 6 carry the same reference numerals.

Figure 7 shows one means for directing or focusing sound energy into a chosen region of the formation wherein piezoelectric crystal 130 is actuated by alternating current source 131 and the vibrational energy generated thereby is reflected from element 132.

Figure 8 shows another means for directing or focusing sound energy into a chosen region of the formation wherein piezoelectric crystals 135 and 136 are actuated by alternating current source 137 and the vibrational energy generated thereby is reflected from element 138.

Figure 9 shows a heater for heating the formation during vibrating and injection of a driving fluid.

In the modification of this invention shown in attached Figure 1, the driving liquid is injected into the formation by means of a sonic pump which also serves to vibrate the oil-bearing formation surrounding and in the neighborhood of the point of entry of the driving liquid, thereby agitating the oil and dislodging it from the less permeable formation and permitting it to be swept by the driving liquid to a conventional production well where it is removed from the formation and transported to the earth surface. The driving liquid itself, together with the pumping unit, function as the transducing medium for transmitting the vibrational energy to the formation and to a block embedded in the formation which provides added coupling to the formation. Sonic pumps which are suitable for use throughout this invention are known and have been described in U. S. Patent 2,355,618 to A. G. Bodine.

Referring more particularly to attached Figure 1, the injection or input well is cased with well casing 26 which extends from the earth surface down to a transducing mass such as cement block 28 containing a duct 37 which permit the flow of driving liquid through ports 30 into oil-bearing formation 32 surrounding the cement block 28. Well casing 26 is fitted at the surface with casing head 25 and packing gland 24. Pump tubing 23 is joined to vibratory housing 35 at junction 22, passes through packing gland 24 and extends almost to the bottom of casing 26, passes through sealing gland 29 and joins the duct system of cement block 28.

Pump tubing 23 is fitted with a number of sonic check valves, only two of which have been shown

as 27 and 27a. The check valves are so positioned in the pump tubing 23 with respect to each other and with respect to junction 22 that when vibrations of the desired sonic frequency are impressed on the system by wave generator 36 there is a net transfer of liquid down the pump tubing 23.

The sonic check valves for causing the downward fluid flow for example, may be spring loaded from the underside to permit the downward liquid flow under the action of a compressional wave from junction 22 and are closed by a wave of rarefaction to prevent the reverse flow. A check valve of this type is shown in Figures 4 and 5. This particular check valve comprises a section of pump tubing 101, the end of which is fitted with a valve plate 102 containing four holes 103 which are located symmetrically about center of the valve plate. The bottom side of each of the four holes is normally covered by a single washer shaped pressure plate 104 which is spring loaded from the lower side. The spring 105 is held in place by a washer 106 and bolt 107 which is threaded into the center of the valve plate 102 from the underside. Under the action of a pressure wave striking the upper or intake side of the valve, the pressure plate 104 is opened to permit a momentary surge of liquid to flow through the uncovered holes 103. Following the liquid surge the pressure plate 104 is pushed against the holes by the action of the spring 105 and prevents the reversed liquid flow until the next pressure wave again opens the pressure plate 104. It is apparent that the inversion of the check valve will produce a net upward fluid flow such as is required to pump liquids from the formation as is hereinafter described.

Referring again to Figure 1, motive means 15 drives wheel 16 through connecting drive belt 35 thereby rotating meshed gears 17 and 18 in opposite directions. Gears 17 and 18 are geared to eccentric heavy masses 19 and 20 respectively, which rotate in opposite directions. The rotation of eccentric masses 19 and 20 is symmetrical and the center of mass of the system has no horizontal movement during the rotational cycle. The net resultant of all horizontal forces is therefore zero. The center of mass for the system is continually shifted along a vertical axis during the rotation of 19 and 20 thereby producing alternate upward and downward thrusts on vibratory housing 36, which is mounted through springs 21 to stationary support 34. Through the rotation of masses 19 and 20, housing 36 is set into sonic vibratory motion at a frequency which is dependent upon the rotational speed of motive means 15.

The driving liquid, which also serves as a transducing medium, flows from storage tank 11 through line 12 controlled by valve 13 into line 14 and into pump tubing 23. The vibration of housing 36 is transmitted through pump tubing 23 and the liquid contained therein. The transmitted waves actuate sonic check valves 27 and 27a as well as the other check valves not shown thereby causing the downward flow of the liquid through tubing 23, the liquid flows through duct 37 and out of ports 30 into oil-bearing formation 32 in surges which are of the same frequency as vibratory housing 36. The pulsating of the tubing and the liquid causes the cement block to vibrate thereby setting up a vibration pattern throughout a surrounding region of formation 32. The vibration of the formation cooperates with the driving force of the liquid to

sweep the oil ahead of the water flow toward the output well.

At some distance from the input well there is located an output well for the removal of the oil which has been dislodged and driven from the formation as a result of the sonic vibrations and liquid drive. The output well is cased with well casing 50 which extends from the surface somewhat into oil-bearing formation 32. The well bore through the oil-bearing formation may be lined with perforated liner 51 containing perforations 53 through which the oil from the oil-bearing formation 32 flows and gathers in liquid pool 63 in the bottom of the well bore. Pump tubing 52 extends into the oil pool 63 and is fitted with standing valve 54 which permits an upward liquid flow and prevents the reverse flow. The upward fluid flow is maintained by traveling valve 55 which is actuated by sucker rod 56 which is in turn actuated by motive means at the earth's surface not shown. Well casing 50 is sealed with casing head 57 which is fitted with packing gland 58 through which pump tubing 52 emerges. The liquid flow from pump tubing 52 enters line 59 controlled by valve 60 and passes through line 61 into product storage tank 62.

In the modification of this invention shown in Figure 2 the driving liquid is introduced into the formation by means of a sonic pump which also serves to impart sonic vibrations to the formation surrounding the point of entry of the driving liquid. The formation is also vibrated by a wave generator through a transducer at a point removed from the input well. The oil-bearing fluid is removed from the output well which is in turn pumped by a sonic pump which also imparts sonic vibrations to the oil-bearing formation surrounding its location.

Referring more particularly to attached Figure 2, the injection or input well is cased with well casing 22 which extends somewhat into oil-bearing formation 28 and is fitted with perforated liner 25 containing perforations 26 through which the driving liquid is forced into oil-bearing formation 28. Well casing 22 is fitted at the surface with casing head 24 and packing gland 20. Sonic pump tubing 23 is fitted at the top with reciprocating piston 18 and the tubing extends through packing gland 20 to near the bottom of the bore hole. The pump tubing 23 is also fitted with several sonic check valves, only two of which are shown as 24 and 24a. These check valves may be spring loaded from the bottom side and open during the compressional wave travelling from the top of the tubing to permit a downward flow of liquid and close on the rarefaction wave to prevent a reverse upward flow. The design and operation of such valves has been described hereinbefore.

Motive means 15 rotates shaft 16 which is coupled to connecting rod 17 by means of an eccentric cam arrangement not shown in detail, which arrangement produces a reciprocating vertical motion to piston 18. The stroke of the piston is adjustable by varying the eccentricity of the cam employed.

The driving liquid, which also serves as a transducing medium, flows from storage tank 11 through line 12 controlled by valve 13 and through line 14 into pump tubing 23 under the sonic pumping action produced by the reciprocal motion of piston 18 on the driving liquid contained in pump tubing 23 wherein the fluid flow is in turn controlled by sonic check valves 24 and 24a and the others not shown. The driving

liquid flows downwardly through pump tubing 23 and into driving liquid pool 29 which is maintained in a vibrating state as a result of sonic waves transmitted from the earth surface through the liquid column. The pulsating and vibrating liquid flows through perforations 26 of perforated liner 25 and into oil-bearing formation 28 wherein it transmits sonic vibrations to the region of the oil-bearing formation surrounding from its point of entry into the formation.

At another location sonic vibrations are transmitted to the oil-bearing formation 28 from a surface wave generator by means of a solid transducer. Motive means 45 rotates wheel 47 through drive belt 46 which causes meshed gears 48 and 49 to rotate in opposite directions. Meshed gears 48 and 49 are coupled to connecting rods 50 and 51 which are in turn attached to shaft 52. The rotation of meshed gears 48 and 49 produces reciprocating vertical drive on shaft 52 which drive is communicated to the heavy mass 53 which is mounted on vertical slide runners 55 and 56 fastened to frame 54. Frame 54 is mounted on vibratory platform 57 which is supported on springs 58 over stationary platform 59 which is firmly positioned on the earth surface. Well bore casing 62 extends from the earth surface through the center of stationary platform 59 somewhat into the oil-bearing formation 28. Coupling rod 63 is attached to vibratory platform 57 by coupling 60 and enters casing 62 through packing gland 61 and extends downward into the proximity of the oil-bearing formation where it is attached by securing members 65 in a block of metal, solidified sulfur, concrete, plastic or other solid transducing mass 64 which is positioned near or in the oil-bearing formation.

The vibration of vibratory platform 57 is induced by the vertical reciprocating motion of heavy mass 53 and is transmitted through coupling rod 63 to transducing mass 64 which in turn couples the vibrations to the oil-bearing formation wherein they radiate outwardly from transducing mass 64.

The output well is cased with well casing 95 which extends from the earth surface somewhat into oil-bearing formation 28. Perforated liner 92 containing perforations 93 is hung from casing 95 and traverses oil-bearing formation 28. The oil flows from oil-bearing formation 28 through perforations 93 into oil pool 94. Motive means 80 rotates shaft 81 which is coupled to connecting rod 82 by means of an eccentric cam not shown, which arrangement produces a reciprocating vertical motion of piston 83. The stroke of piston 83 is varied by adjusting the eccentricity of the cam employed. The reciprocation of piston 83 impresses sonic mechanical vibrations on the liquid medium contained in pump tubing 84 which tubing is fitted with several sonic check valves, only two of which are shown as 91 and 91a. Check valves 91 and 91a may be spring loaded from the upper side and permit the upward flow of liquid but prevent the reverse liquid flow. For such purposes check valves of the type hereinbefore described may be mounted in an inverted position. The spacing and location of the check valves is dependent upon the vibration frequency employed being such that there is a net transfer of liquid up the pump tubing under the action of the vibrations employed. Oil flows from pool 94 through pump tubing 84 into line 87 controlled by valve 88 and through line 89 into oil storage tank 90. The reciprocation of piston 83 induces mechanical

vibrations throughout the liquid medium in pump tubing 84 and into oil pool 94 from which they are transmitted to the oil-bearing formation surrounding oil pool 94. The impression of vibrational energy on the oil-bearing formation improves the transport of oil from the oil-bearing formation into the oil pool.

In the modification of this invention shown in Figure 3 the driving liquid is introduced into the formation by means of a conventional reciprocating pump, wherein the formation is vibrated by means of a wave generator and a transducer, the latter being coupled to the formation at a location away from the input well and in the general direction of an output well, and the oil-bearing fluid is removed from an output well which employs a conventional reciprocating pump for pumping the oil from the oil-bearing formation. This arrangement of equipment is most often applicable to producing formations which have been abandoned or which are nearing abandonment. In these instances the wave generator is usually coupled to the formation through an existing well bore and existing pumping equipment is reconverted to the liquid flooding operation. This modification of the invention is not to be construed as limited to such circumstances since it can be employed during the flooding of even virgin fields if desired.

Referring more particularly to attached Figure 3, the injection or input well is cased with well casing 26a from which is suspended perforated liner 25 containing perforations 26, which liner traverses at least a part of oil-bearing formation 32. At the surface the well is closed with casing head 25a which is fitted with packing gland 24 through which pump tubing 23 extends to the bottom of the well. Sucker rod 15 is actuated by motive means not shown and extends through pump tubing 23 to a point near the bottom of the well where it is fitted with traveling valve 16. Stationary valve 17 is located in pump tubing 23 below traveling valve 16. Valves 16 and 17 provide for the downward flow of liquid but prevent the reverse upward flow.

Driving liquid is pumped from storage tank 11 through line 12 controlled by valve 13 through line 14 and into pump tubing 23 through which it passes to the bottom of the well and is pumped by means of the mechanism previously described through driving liquid pool 18 through perforations 26 and into oil-bearing formation 32.

Wave generator 34 is actuated by motive means 35 through pulley 36 which causes the rotation of cam 37 which effects the vertical movement of roller bearing 38 resting on cam 37. Cam 37 is preferably of suitable size and shape to produce substantially a simple harmonic vertical movement of roller bearing 38. In certain instances however, such as when it is desired to vibrate the formation with a complex wave train, the cam may be of suitable size and shape to effect the production of these waves. Roller bearing 38 is fastened to rod 39 which is pivoted about point 40 and is counterbalanced by adjustable weight 41. Coupling rod or pipe 43 is attached to rod 39 by pivot 42. The rotation of cam 37 produces a reciprocating motion of rod 39 through bearing 38 which motion is commuted to conducting rod or pipe 43 and the elements to which rod or pipe 43 is coupled.

The vibrational transmission bore hole is lined with casing 46 which casing is closed at the surface by casing head 45 which casing head is fitted with packing gland 44 through which coupling

rod or pipe 43 moves freely. Casing 46 is fitted near the bottom of the well with mounting 33 which is fitted with packing gland 47 through which conductor 43 is permitted to move. Radiation surface 48 is attached to the lower end of conductor 43 and radiates the transmitted wave energy from wave generator 50 to transducing medium 49. The transducing medium is, for example, water, crude oil, molten sulfur, low melting alloys, mercury or any other suitable liquid for the transmission of vibrational energy from radiation surface 48 to the surrounding oil-bearing formation 32. The conical shape of radiation surface 48 and the vertical reciprocating motion produced by wave generator 34 results in a series of horizontal vibrational waves which agitate the liquids in the surrounding formation and assist in the stripping action of the liquid flooding for removing oil from the formation. Radiation surfaces other than cones such as discs, ellipses and the like may also be employed.

At some distance from the input well there is located an output well for the removal of the oil which has been dislodged and driven from the formation as a combined result of the vibrations and liquid drive. The output well is cased with well casing 50 which extends from the surface somewhat into oil-bearing formation 32. The well bore through the oil-bearing formation may be lined with perforated liner 51 containing perforations 53 through which the oil from the oil-bearing formation 32 flows and gathers in liquid pool 63 in the bottom of the well bore. Pump tubing 52 extends into the oil pool 63 and is fitted with standing valve 54 which permits an upward liquid flow and prevents the reverse flow. The upward fluid flow is maintained by traveling valve 55 which is actuated by sucker rod 56 which is in turn actuated by motive means at the earth surface not shown. Well casing 50 is sealed with casing head 57 which is fitted with packing gland 58 through which pump tubing 52 emerges. The liquid flow from pump tubing 52 enters line 59 controlled by valve 60 and passes through line 61 into product storage tank 62.

The foregoing description and discussion of this invention has been primarily directed toward the application of sonic waves to improve liquid flooding operations. However, it is understood that my invention may employ either sonic or supersonic waves, and that such vibrational waves may be employed in both liquid flooding and gas drive secondary recovery operations in order to dislodge and strip oil from an oil-bearing formation.

Frequencies in the subsonic and lower sonic range of about 10 to 5,000 and preferably 20 to 2,000 cycles per second provide the greatest amount of agitation of the oil in an oil-bearing formation with a minimum loss of mechanical energy to the production of heat. Vibrations of these frequencies which are sinusoidal in nature are easily generated by mechanical means such as have been described hereinbefore and can be employed to establish resonant vibratory states in most oil-bearing formations. Lower frequency waves are most useful in dislodging higher gravity crude oils such as those whose A. P. I. gravity at 60° F. is greater than about 20 in which case mechanical energy alone suffices to dislodge the trapped oil particles.

In certain other cases, such as when the crude oil to be dislodged has an A. P. I. gravity at 60° F. of less than 20, it is desirable to employ high frequency vibrations in the upper sonic and/or

in the supersonic range such as between about 5,000 and 100,000 or higher in order to heat and agitate the formation simultaneously thereby decreasing the viscosity of the crude oil and rendering it more susceptible to the purging action of the driving liquid or gas. The heating of the formation by upper sonic and/or supersonic vibrations has the advantage over heat transfer type heating agents such as steam, hot water, and the like, in that the problem of heat transfer through poorly conductive formations is largely eliminated. It is apparent, however, that vibrational shaking with or without heating by vibration together with heating by heat transfer means, such as is shown in Figure 9, may be employed conjunctively in the application of this invention wherever this is desirable for economic or other reasons.

Vibrations in the upper sonic and supersonic range for use in agitating and/or heating oil-bearing formations can be generated, such as in Figure 7, by impressing a high frequency alternating electrical current from source 131, produced by suitably amplifying the high frequency currents produced by a vacuum tube oscillator, across the polar axis of a piezo-electric quartz crystal 130 whereby the crystal is set into vibratory motion at a frequency dependent upon the frequency of the alternating current and the size of the crystal. Such vibrations can also be produced by placing, such as is shown in Figure 6 for example, a nickel rod 124 having magnetostrictive properties in a high frequency alternating magnetic field produced by impressing a high frequency alternating current from source 122 across a suitably designed coil 123. Vibrations transmitted from nickel rod 124 to coupling rod 63 are then transmitted to the oil-bearing formation 28 in the manner which was described hereinbefore in connection with Figure 2. The construction of these and other devices is well known in the art.

In certain instances it is desirable to employ complex or modulated vibrational waves derived from the combination or addition of two or more sinusoidal waves of dissimilar frequencies. The component waves of the complex wave may, for example, bear a harmonic relationship to each other, i. e., the frequency of all but one of the component waves may be an integral multiple of the frequency of the one fundamental wave. As an example of the use of such compounded wave forms, a fundamental sonic wave is generated with any suitable generator and is transmitted to the formation through a transducer. A second wave generator is employed to generate a wave having a frequency of, for example, 7, 8, 9, or 10 times that of the fundamental frequency and is also coupled to the formation by a separate transducer or by a transducer which is also common to the generator producing the fundamental frequency. Figure 2 shows a modification of the invention wherein a total of three sonic wave generators are employed which may be employed for the generation of compounded wave forms. The fundamental sonic wave generated by one of the generators, such as by the actuation of motive means 45, is transmitted to the formation through transducing mass 64. A second wave generator actuated by motive means 15 is employed to generate a wave having a frequency of 7, 8, 9 or 10 times that of the fundamental frequency. The second wave generator is coupled to the formation through the transducing medium of the water being injected. The third wave generator actu-

ated by motive means 80 and coupled to the formation through the liquid medium of the oil being produced from the formation may be operated at any desired frequency which may, or may not, be the same as that of either of the first two wave generators. The formation is vibrated by the higher frequency wave and intermittently receives a boost or kick vibration as a result of the pressure wave of the lower frequency vibration. Complex waves of this type are often more effective than simple sinusoidal waves and particularly in those formations where resonant vibratory conditions are difficult to establish. It is apparent that the relative amplitude of each of the wave forms can be varied in order to provide the maximum amount of agitation within the formation as is evidenced by the increased rate of oil production at the output well or wells.

It is apparent from the foregoing illustrations of this invention that I may employ one or more sonic or ultrasonic vibrational generators and transducers to vibrate an oil-bearing formation from one or more locations. Such vibrations may be of identical or differing frequencies such as has been discussed hereinbefore. In the event that the vibrations are all the same frequency, or possess frequencies which are simple integral multiples of the frequency of one of the vibrations, it is desirable but not necessary that a condition of synchronism exist between the transducers of the various sources of vibration in the formation through the coupling action of the formation. Where conditions are conducive to the establishment of a condition of resonance the motive means of the generators tends to convert to a resonant condition. Any tendency towards departure from resonant state results in a marked decrease of the load on the motive means, thereby tending to speed up the motive means in order to maintain or establish the resonant condition. At the resonant state, the accumulated mechanical energy in the formation increases to a value considerably in excess of that which is supplied to the system with the result that a maximum agitation of the oil particles in the formation is obtained at the resonance state for a given amount of vibrational energy supplied to the system.

Although the transducers described hereinbefore in connection with attached figure are useful in the application of this invention, other transducers may be employed which direct and focus the vibrational energy along a given band or zone. Thus, radiators or reflectors may be placed in the formation and coupled to or used in conjunction with transducers, such as those radiators or reflectors which are substantially parabolic troughs as shown in Figure 8. The vibrations radiating and/or reflected by such radiators are focused in a controlled band and can be focused or beamed in any direction toward any desired objective. Similarly, radiators or reflectors can be employed which are paraboloids or paraboloidal in nature, as shown in Figure 7, in order to focus and direct the waves in a beam along a predetermined direction or toward a desired objective. Such radiators or reflectors should be of such dimensions that the effective focal length of the paraboloids in place in the formation is about one-quarter of the wave length of vibration being employed or an odd multiple thereof.

Although most of the foregoing discussion and description has pertained to the use of both sonic and supersonic vibrations in conjunction with

liquid flooding operations, the use of vibrational energy is equally applicable to gas drive operations. Gaseous media tend to absorb both sonic and supersonic vibrations with an attendant generation of heat and diminution of the wave intensity. Accordingly, in gas drive operations it is desirable that the sonic or supersonic generator and transducer be located between the injection and output wells in such a manner that the transducer contacts substantially a liquid phase, thereby facilitating the transmission of the undiminished wave front throughout the liquid phase of the oil-bearing formation. Operation at high pressures also facilitates the transmission of the vibrations through the gaseous phase. Under these conditions there is a minimum conversion of the mechanical energy to heat and a maximum utilization of the vibrational energy for the agitation of the formation at a given wave energy input. The situation is shown in Figure 6, which is a modification of the invention shown in Figure 2, wherein the liquid injection system on the far left-hand side of Figure 2 is replaced by a gas injection arrangement 121 of the type normally employed in gas drive operations for forcing air, flue gas, natural gas and the like supplied through line 120 into oil-bearing formation 28, and wherein a wave generator of the magneto-strictive type is employed to vibrate oil-bearing formation 28 as described hereinbefore.

Having fully described and illustrated my invention I claim:

1. A process for the production of petroleum which comprises generating vibrations of a lower frequency with one wave generator, generating vibrations of a higher frequency with a second wave generator, coupling both generators to an oil-bearing formation thereby vibrating said oil-bearing formation with a non-sinusoidal vibrational wave, forcing a driving fluid through said oil-bearing formation simultaneously with said vibrating, and producing oil from said oil-bearing formation.

2. The process of claim 1 wherein the driving fluid is water.

3. In a secondary recovery process wherein a driving fluid is forced into an oil-bearing formation through an input well and petroleum is recovered from an input well located some distance from said input well, the improvement which consists in locating a first vibrational wave generator at the earth's surface adjacent to said input well, coupling said first generator to the oil-bearing formation adjacent said input well, locating a second vibrational wave generator at the earth's surface adjacent said output well, coupling said second generator to the oil-bearing formation adjacent said output well, and simultaneously generating vibrational waves by means of said first and second generators while said driving fluid is forced into the oil-bearing formation through said input well and while said petroleum is recovered from said output well, said generators being operated at different frequencies thereby vibrating said oil-bearing formation with a non-sinusoidal vibrational wave substantially continuously during the forcing of said driving fluid thereinto and during the recovery of petroleum therefrom.

4. The process of claim 3 wherein the driving fluid is water.

5. In a secondary recovery process wherein a driving fluid is forced into an oil-bearing formation through an input well and petroleum is recovered from an output well located some dis-

tance from said input well, the improvement which consists in locating a first vibrational wave generator at the earth's surface adjacent to said input well, coupling said first generator to the oil-bearing formation adjacent said input well, locating a second vibrational wave generator at the earth's surface adjacent said output well, coupling said second generator to the oil-bearing formation adjacent said output well, locating a third vibrational wave generator at the earth's surface adjacent a third well penetrating the oil-bearing formation at a point intermediate between said input and output wells, coupling said third generator to the oil-bearing formation adjacent said third well, and simultaneously generating vibrational waves by means of said first, second and third generators while said driving fluid is forced into the oil-bearing formation through said input well and while said petroleum is recovered from said output well, at least two of said generators being operated at different frequencies thereby vibrating said oil-bearing formation with a non-sinusoidal vibrational wave substantially continuously during the forcing of said driving fluid thereinto and during the recovery of petroleum therefrom.

6. The process of claim 5 wherein the driving fluid is water.

7. In a secondary recovery process wherein a driving fluid is forced into an oil-bearing formation through an input well and an effluent fluid is recovered from an output well located some distance from said input well, the improvement which consists in coupling a vibrational wave generator to the driving fluid in said input well, coupling a second vibrational wave generator to the effluent fluid in said output well, and simultaneously generating vibrational waves by means of said vibrational wave generators while said driving fluid is being forced into said formation through said input well and while said effluent fluid is recovered from said output well, said

wave generators being operated at different frequencies and thereby vibrating said formation with a non-sinusoidal vibrational wave substantially continuously during the forcing of said driving fluid thereinto and during the recovery of petroleum therefrom.

8. In a secondary recovery process wherein a driving fluid is forced into an oil-bearing formation through an input well and an effluent fluid is recovered from an output well located some distance from said input well, the improvement which consists in coupling a vibrational wave generator to the driving fluid in said input well, coupling a second vibrational wave generator to the effluent fluid in said output well, coupling a third vibrational wave generator to said formation at an intermediate point between said input and output wells, generating vibrational waves by means of said three vibrational wave generators while said driving fluid is being forced into said formation through said input well and while said effluent fluid is recovered from said output well, at least two of said three vibrational wave generators being operated at different frequencies thereby vibrating said formation with a non-sinusoidal vibrational wave substantially continuously during the forcing of said driving fluid thereinto and during the recovery of petroleum therefrom.

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