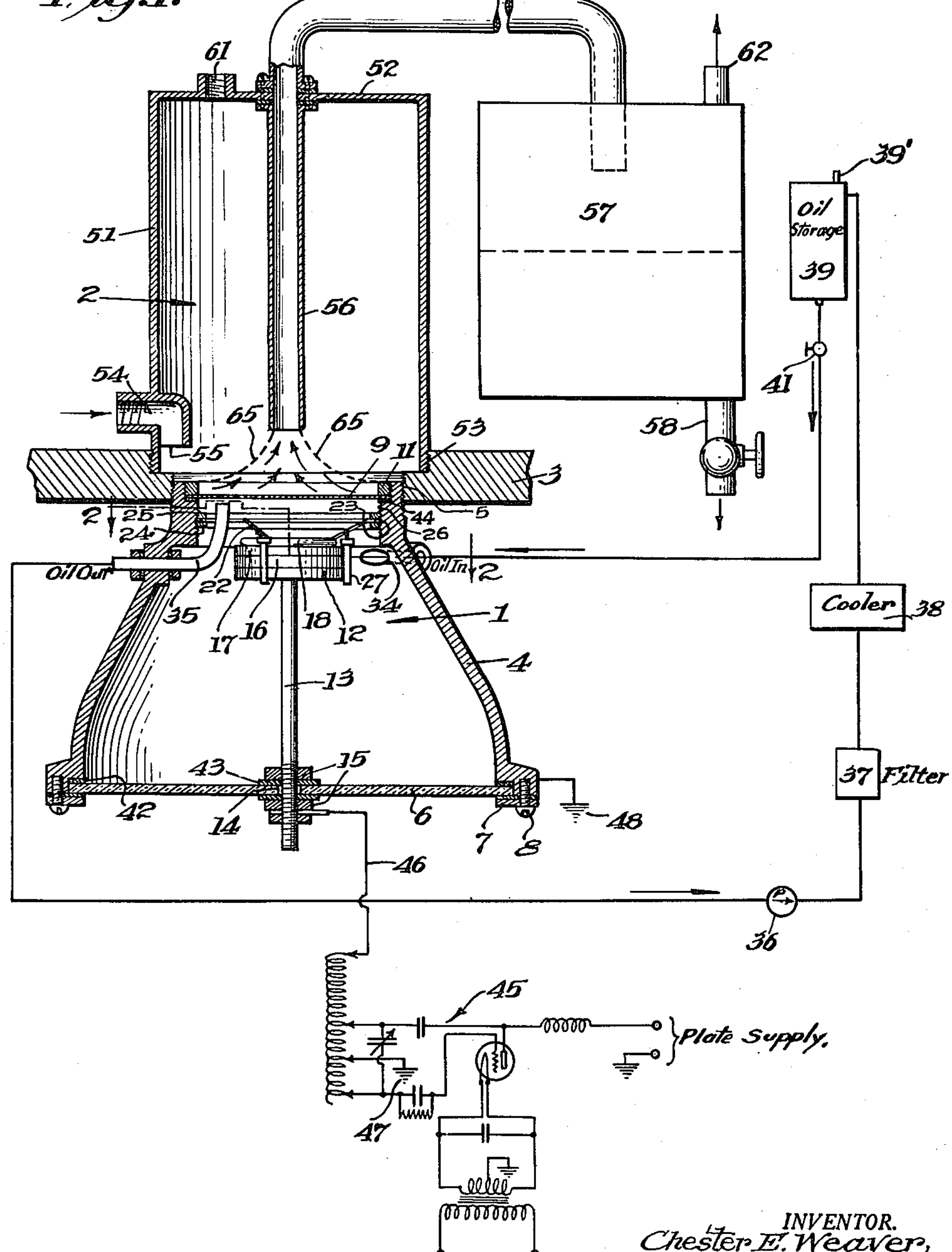
June 27, 1939. C. E. WEAVER 2,163,649

METHOD AND APPARATUS FOR UTILIZING HIGH FREQUENCY COMPRESSIONAL WAVES

Original Filed Nov. 25, 1935 2 Sheets-Sheet 1

Fig. 1.



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Original Filed Nov. 25, 1935 2 Sheets-Sheet 2

Fig. 2.

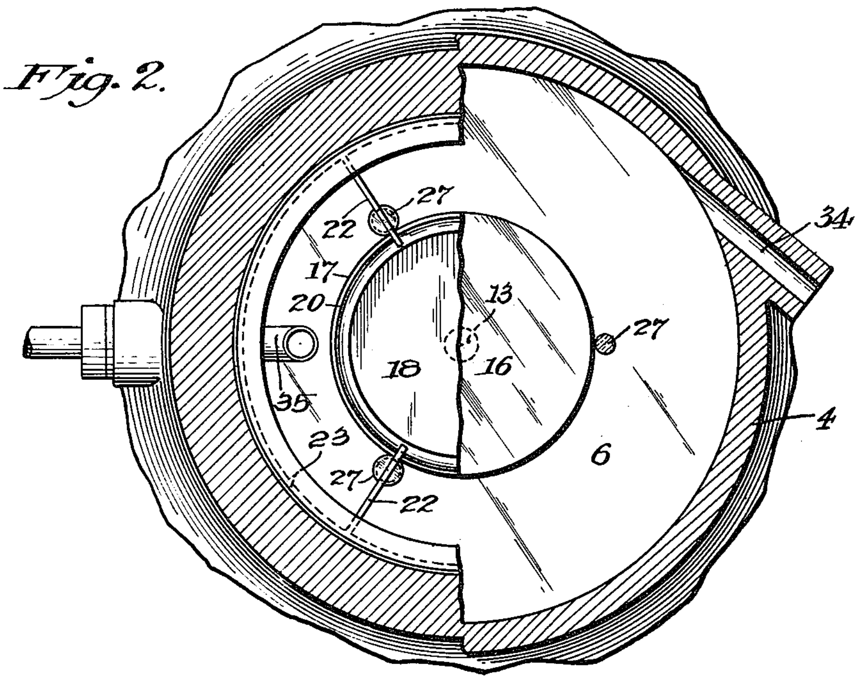


Fig. 3.

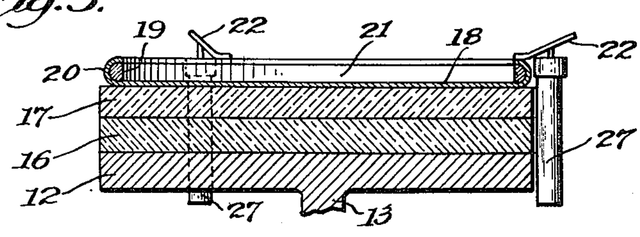
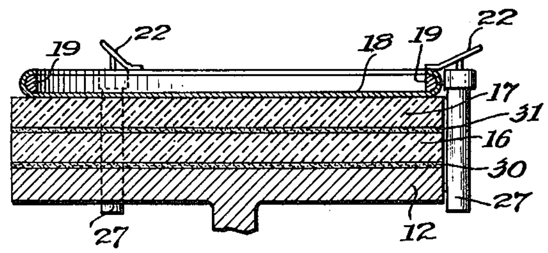


Fig. 4.



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2,163,649

METHOD AND APPARATUS FOR UTILIZING HIGH FREQUENCY COMPRESSIONAL WAVES

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Application November 25, 1935, Serial No. 51,552
Renewed September 12, 1938

9 Claims. (Cl. 259—72)

This invention relates to the production and utilization of high frequency compressional waves. More particularly, the invention includes a method and apparatus for producing high frequency compressional waves, or ultrasonic vibrations, dependent upon the piezo-electric properties of certain crystalline materials, and also a method and apparatus for utilizing high frequency compressional waves or vibrations produced by any suitable means, for treatment of fluid materials.

In general, the method and apparatus of this invention may be employed in the production and/or utilization of compressional waves at any frequency above the range of audibility for the human ear, or upward of 20,000 to 25,000 cycles. The frequency employed may be selected in accordance with the purpose for which the compressional waves are to be employed. Thus, for many uses, frequencies of from 50,000 to 500,000 may be employed. For other purposes, as hereinafter pointed out, I prefer to employ frequencies on the order of 1,000 kilocycles or above.

If a crystal having piezo-electric properties is properly cut, with relation to its electrical axes, and then subjected to a high-frequency electric field at a suitable frequency selected in accordance with the dimensions of the crystal, the crystal exhibits a rapid alternating expansion and contraction in a direction perpendicular to the two opposing faces between which said field is maintained, so that, if a fluid medium is maintained in such position as to be affected by the movement of one of said faces, high frequency compressional waves are produced in said fluid medium. Each crystal possesses a certain natural resonant frequency, dependent upon the thickness of the crystal, and the energy or intensity of the vibrations produced is a maximum when the frequency of the applied electric field corresponds to this resonant frequency.

It has been heretofore proposed to utilize high frequency compressional waves produced in this manner for various purposes, such as for sterilization of liquids or formation of colloidal suspensions or emulsions. However, in order to obtain effective results in such methods of treatment, it is necessary to have the frequency of the applied voltage substantially equal to the natural resonant frequency of the piezo-electric crystal. Heretofore, serious difficulties have been experienced due to building up of the expansive and contractive movements of the crystal under resonant conditions, resulting in stressing of the crystal beyond its elastic limit, and consequent fracture or disintegration of the crystal.

The use of oil as a damping medium has been suggested, but I have found that the use of oil for this purpose is ineffective at high powers.

One of the principal objects of this invention is to provide for the piezo-electric production of high frequency compressional waves in such manner as to generate waves of very high intensity, while substantially eliminating or materially decreasing the tendency of the piezo-electric crystal system to fracture or disintegrate. According to my invention this object is attained by employing a plurality of crystals, to which the high frequency electric field is applied in series. By using a piezo-electric system comprising two or more piezo-active crystals arranged in series in a high voltage high frequency electric field, I have found that very powerful high frequency vibrations can be produced, uniformly and continuously for relatively long periods, without fracturing or disintegrating the crystals of said system.

I am not prepared to state with certainty the exact nature of the phenomenon involved in such a multiple crystal system, and the invention is not to be regarded as restricted to any definite theory of operation. However, the results I have obtained indicate that, when the applied voltage is in resonance with one of the crystals, the other crystal or crystals act as a damping means for said one crystal, tending to prevent excessive distortion or building up of oscillation at its normal resonant frequency. Thus, by maintaining the frequency of the applied electric field equal to the resonant frequency of one of the crystals, I am able to obtain intense high frequency vibrations and to produce high frequency compressional waves of high intensity, without resulting in such sharp or violent vibrations as to tend to shatter or break the crystal system or any element thereof.

A further important object of the invention is to provide a method and apparatus for continuously subjecting fluid materials to the action of high frequency compressional waves. With this object in view, the invention comprises a method in which such compressional waves, produced piezo-electrically or in any other suitable manner, are established in a body of fluid in a treatment zone, and said fluid is continually supplied to and withdrawn from said treatment zone in such manner as to cause all portions of the fluid to be subjected to the compressional wave system in said zone, and also comprises an apparatus for carrying out said method, in which the fluid is continually withdrawn from the fluid body, or continually introduced thereto, through a passage communicating with the fluid body at a position within the region of the compressional wave system, and preferably adjacent a point of intense compressional wave action.

The treatment of a fluid in this manner may be applied to either liquids or gases, or to fluent mixtures of liquid and solid materials, gaseous and solid materials, or gaseous and liquid materials. It may be employed for any purpose to which ultrasonic vibration treatment is adapted, such as sterilization by means of the destructive action of such vibrations on bacteria or other minute organisms in a fluid medium, or the formation of emulsions by means of the dispersing action of such vibrations on a mixture of two or more liquids, or a mixture of one or more solids and one or more liquids. Other possible uses thereof will be mentioned hereinafter.

Additional features of the invention, and other objects and advantages thereof, will be described hereinafter or will be apparent from the following description.

The accompanying drawings illustrate a form of apparatus embodying piezo-electric generating means, and means for utilizing high frequency compressional waves for continuous treatment of fluid materials, in accordance with this invention, and referring thereto:

Fig. 1 is a vertical sectional view of such an apparatus, partly in elevation, with an electrical energizing circuit and dielectric fluid circulating means shown diagrammatically;

Fig. 2 is a horizontal section on line 2—2 in Fig. 1;

Fig. 3 is an enlarged vertical section of the piezo-electric crystal system and adjacent parts; and

Fig. 4 is a view similar to Fig. 3, showing a modified assembly of the crystals.

The apparatus includes, in general, two main parts, a compressional wave generating unit indicated generally at 1, and a fluid treatment chamber indicated generally at 2, both of which are shown as inter-connected and supported by a supporting member 3.

The generating unit comprises a housing 4 of circular cross-section, having fairly heavy rigid side walls, whose upper end is threadedly or otherwise rigidly secured as at 5 to the supporting member 3. Said housing may conveniently be formed of metal and is preferably, but not necessarily, of the general shape shown in Fig. 1, having its lower end of somewhat greater diameter than its upper end, and its side walls sloping inwardly and upwardly.

A bottom plate 6 of glass or other insulating material extends across the lower end of said housing, being secured thereto as by means of retaining ring 7 and screws 8. Said bottom plate is of sufficient thickness and rigidity to remain substantially stationary under the high frequency expansion and contraction of the crystal system supported thereby, as hereinafter described. The upper end of said housing is closed by a thin diaphragm 9 of tough, resilient metal which may comprise, for example, a disc of stainless steel having a thickness of about .001 to .0015 inch. The metal of which the diaphragm is made should be one which is sufficiently resistant to the liquid which is to be treated. Said diaphragm is rigidly secured at its periphery to the upper portion of the housing 4, as by means of a threaded ring 11.

A lower electrode 12 is supported within the housing 4, preferably substantially centrally thereof and a suitable distance below the diaphragm 9. Said lower electrode is preferably formed of metal and may be of any suitable shape. It is shown as a cylindrical member, supported by a depending rod or post 13 formed integrally therewith, and of much less diameter than the electrode, said rod being in turn secured at its lower end to the central portion of the bottom plate 6 which serves to insulate said rod and the electrode 12 from the housing 4 and from ground. In order to permit vertical adjustment of electrode 12, the rod 13 is shown as extending loosely through a central opening 14 in the bottom plate 6 and secured to said plate by means of two clamping nuts or members 15 threadedly engaging said rod. By mounting the lower electrode on a supporting member of relatively small diameter, such as rod 13, and further, by enlarging the diameter of the lower end of the housing, I am enabled to provide a sufficient length of insulation 6 between this electrode and the housing to avoid leakage of current through or along the surface of said insulation, at the high voltage employed.

The piezo-electric crystal system is supported upon the lower electrode 12. Said crystal system may comprise two or more superposed crystals of quartz or other piezo-active material, preferably of good mechanical ruggedness, such as tourmaline, beryl, or topaz. In Figs. 1 and 3 I have shown two such crystals, 16 and 17, and said crystals are preferably of circular shape, having their upper and lower faces carefully ground so as to be substantially plane and parallel to one another and properly disposed with respect to the electrical axes of each crystal. The upper face of the lower electrode is preferably also provided with a substantially plane surface.

Another electrode 18 is provided above the piezo-electric crystals, so that the two or more crystals are interposed in series in the high frequency electrical field established between electrodes 12 and 18. The upper electrode 18 is preferably of thin metal, and is shown as a thin metal disc whose edge portion is bent up around a ring 19 of semi-circular cross-section, so as to present a rounded edge 20 serving to prevent any undue concentration of the electrical field intensity at said edge portion, while at the same time providing a substantially straight-sided cylindrical open space 21 above the electrode surface to permit unimpaired propagation of high frequency compressional waves upwardly through the fluid medium in contact therewith. The electrode 18 is supported in such manner as to permit vibration thereof. For this purpose, said electrode may be secured, as by welding, to the inner ends of three supporting arms 22 formed of light resilient wire, whose outer ends are secured to a supporting ring 23. To provide for vertical adjustment of the upper electrode, the supporting ring 23 is shown as secured between two externally threaded clamping rings 24 and 25 which engage internal threads 26 on the upper portion of housing 4.

Means are preferably provided for holding the crystals in proper position between the electrodes. Such means may comprise three positioning rods 27 of glass or other insulating material, secured to and depending from the supporting arms 22, and engaging the peripheral edges of said crystals in such manner as to permit vertical vibration of said crystals while preventing lateral displacement thereof.

In Fig. 3, the electrode 12, crystals 16 and 17, and electrode 18, are shown as being in direct contact with one another, each member of this system resting directly upon the one below it. However, it is within the scope of this invention to provide a thin layer or sheet of metal or other electrically conductive material between the two crystals. Also, it may in some cases be advantageous to provide thin layers or strips of cushioning material, such as felt or the like, between two or more of these members. For example, in Fig. 4, I have shown layers of felt or the like, between the lower electrode and the lower crystal and also between the two crystals, as at 30 and 31, respectively. When this arrangement is employed, the upper electrode 18 is preferably so adjusted as to compress or pack the cushioning layers 30 and 31 to a considerable degree, so that they are substantially resistant to deformation under the normal vibration intensity of the crystals, but are still adapted to yield somewhat in case the vibrations become too intense, and thus serve to protect the crystals against excessive shock.

A body of oil or other liquid of high dielectric strength, and preferably of relatively low vapor pressure at ordinary temperatures, is maintained within the housing 4 and around the piezo-electric crystals and the electrodes associated therewith, and means are preferably provided for continually circulating said liquid through said housing and through external cooling means, to prevent overheating of the crystals and electrodes and the dielectric medium by the considerable heat evolution which accompanies the high frequency vibration of the crystals. Furthermore, the liquid circulating means are preferably such as to maintain active circulation or swirling movement of the liquid within the housing 4, particularly in the vicinity of the crystals. For this purpose, housing 4 may be provided with a tangentially directed inlet opening 34, or with a plurality of such openings, preferably at about the mid-height of the crystal system, and with an outlet pipe 35, preferably opening into the interior of the housing immediately below the diaphragm 9 so as to maintain the housing substantially filled with liquid up to said diaphragm.

The circulating system, as shown diagrammatically in Fig. 1, may comprise a pump 36 whose inlet is connected to the outlet pipe 35 and whose outlet is connected through a filter 37 and cooling means 38 to a storage receptacle 39, whence the liquid is supplied through valve 41 to the inlet opening 34. The interior of housing 4 is made fluid-tight, suitable gaskets being provided where necessary for this purpose, as indicated at 42, 43, and 44.

The electrodes 12 and 18 are connected to a suitable source of high frequency electric current at high voltage, preferably in excess of 10,000 volts, and more preferably 50,000 volts or greater. Said source may comprise a "Hartley oscillator" or other vacuum tube oscillating circuit, indicated generally at 45, whose plate circuit may be connected to a suitable source of high voltage electrical power. One output terminal of this oscillating circuit may be connected by conductor 46 to the lower end of supporting rod 13 and thence to the electrode 12 which is maintained at high potential, while the other terminal may be grounded as at 47, the electrode 18 being also grounded through housing 4, as indicated at 48. In case the housing is of non-conducting material, a suitable conductor may be provided, extending through the housing, for grounding the upper electrode.

The fluid treatment chamber 2 may comprise a suitably shaped receptacle 51 having an upper end wall 52, said receptacle being threadedly or otherwise secured at its lower end to the supporting member 3, as at 53, so that the interior thereof is directly above the diaphragm 9. The fluid to be treated is supplied to the interior of said receptacle, preferably at a position near the bottom and adjacent the periphery thereof. For this purpose, the receptacle is shown as provided with a fluid inlet passage 54 communicating with the interior thereof through a downwardly directed opening 55, and said passage may be connected to any suitable source of fluid material to be treated. A fluid outlet pipe 56 is provided, communicating with the interior of the treatment chamber at a position somewhat above the center of the diaphragm 9 and within the region of the high frequency compressional waves produced within the fluid in said chamber. Suitable means are provided for maintaining a continual fluid flow through the inlet and outlet passages, whereby all of such fluid is caused to pass through a treatment zone within the treatment chamber and is therein subjected to the action of high frequency compressional waves.

The apparatus shown is intended particularly for treatment of liquid materials. In this case, the outlet pipe 56 is shown as extending upwardly through the upper end wall 52 and thence into a receiving chamber 57 provided with a valved liquid discharge pipe 58. The chambers 2 and 57 are provided at their upper ends with openings 61 and 62 respectively, and a sufficient pressure difference is maintained therebetween to provide a continual flow of liquid at the desired rate from chamber 2 through pipe 56 to chamber 57. For this purpose, I may maintain a super-atmospheric pressure at opening 61 and leave opening 62 open to the atmosphere, or may leave opening 61 open to the atmosphere and maintain a sub-atmospheric pressure at opening 62, or may maintain both a super-atmospheric pressure at 61 and a sub-atmospheric pressure at 62.

The operation of the above-described apparatus, for the production of high frequency compressional waves and utilization thereof in continuous treatment of liquids, is as follows. The interior of housing 4 being filled with a dielectric liquid medium, such as oxylol, kerosene, or white mineral oil, and circulation of such medium being established through the circulating and cooling system above described, the oscillating circuit 45 is operated to supply high frequency current at high voltage to the opposing electrodes 12 and 18, thus creating a high frequency high potential electric field through the crystals 16 and 17 in series, and causing said crystals, or one of them, to undergo expansion and contraction at high frequency.

For some purposes, such as the killing of bacteria, the frequency should be above 600 kilocycles, and preferably 750 kilocycles or above, and each of the crystals is made of such dimensions as to have the desired resonant frequency. For example, I may use two or more crystals each having a thickness of about 3 mm., whose resonant frequency is in the neighborhood of 1000 kilocycles.

In general, however, I may use crystals having any desired dimensions, to produce compressional waves of any desired frequency above 20,000 to 25,000 cycles. The crystals preferably have resonant frequencies relatively close together, but differing slightly from one another, so that when one crystal is in resonance the other is slightly out of resonance. The oscillating circuit is so adjusted as to supply electricity at the resonant frequency of one of the crystals, which may be accomplished by varying the frequency of the oscillating circuit until the intensity of the resulting high frequency compressional waves reaches a maximum. When so adjusted, the other crystal or crystals of the system, being somewhat out of resonance, serve as damping means for the crystal which is in resonance, and prevent fragmentation or shattering of the driving or resonant crystal.

The high frequency vibratory movement thus produced in the crystal system is transmitted through the upper electrode member 18 and serves to produce high frequency compressional waves in the dielectric medium above said electrode. This motion is communicated through said dielectric medium to the diaphragm 9, causing said diaphragm to also vibrate at high frequency.

The liquid material to be treated is now introduced into the treatment chamber 2, above the diaphragm 9, and the high frequency vibration of said diaphragm produces a system of high frequency compressional waves within said liquid above the diaphragm, producing alternate regions of rarefaction and compression therein. The effect of these high frequency compressional waves produces a marked agitation of the liquid and causes the same to be projected upwardly in the region above the central portion of the diaphragm where the intensity of the compressional waves is a maximum. The surface of the liquid assumes a general cone shape, as indicated in a general way by the dotted lines 65. If the liquid is continually introduced through inlet passage 54 into the treatment chamber 2, and withdrawn therefrom through pipe 56 into chamber 57, such liquid will be caused to all pass through the wave system in the region included between and below the dotted lines 65, before entering the lower end of pipe 56, so that all the liquid is subjected to effective treatment by the high frequency compressional waves, in a continuous treating process.

By maintaining a suitable drop in pressure between the interior of chamber 2 and chamber 57, the liquid may be continually displaced from one chamber to the other at a rate equal to the rate of introduction of liquid into chamber 2, and the rate of flow may be so adjusted as to provide a sufficient time of exposure of the liquid to the compressional waves to effect the desired treatment. The pressure difference required for this purpose may be maintained, for example, by maintaining a slight vacuum at opening 62 and leaving opening 61 open to the atmosphere or connecting the latter to a source of any desired gas, or by leaving opening 62 open to the atmosphere and connecting opening 61 to a source of air or other gas under suitable pressure. In any case, the treated liquid transferred through pipe 56 collects in chamber 57 and may be withdrawn therefrom continually or intermittently through pipe 58.

The continual circulation of externally cooled dielectric liquid through the housing 4 serves to prevent undue heating of the crystals and of the liquid surrounding the same, thus enabling the crystals to operate effectively for a long period of time. Each time this dielectric liquid is withdrawn from the apparatus by pump 36 it is cleaned by passing through filter 37 and cooled by cooling means 38, so that the liquid supplied to the apparatus from chamber 39 is at all times clean and cool. Furthermore, the active whirling motion of the liquid around the crystals due to the tangential introduction thereof serves to quickly remove from the vicinity of the crystals and electrodes any gas bubbles formed by the "cavitation" action of the compressional waves on the liquid, and thus prevents arcing or disruptive discharge between the electrodes, which tends to occur if such liberated gas is permitted to accumulate. Any gas thus formed is carried by the liquid out of the generator chamber, and may be vented from the system in any suitable manner, as by providing a gas vent in the upper portion of storage chamber 39, as indicated at 39^1.

Treatment of liquid materials in the manner above described may be employed for various purposes, such as for sterilization by killing bacteria or other minute organisms in a liquid medium, or for the formation of emulsions.

As an example of the use of this invention for sterilization of liquids, milk containing bacteria may be treated as above described, using compressional waves having a frequency of 600 kilocycles or more, and preferably on the order of 1000 kilocycles, and a very high proportion of the bacteria killed, rendering the milk substantially sterile.

As another example, a mixture of oil and water may be passed through the treatment chamber and converted into a stable emulsion.

It will be understood that the particular form of apparatus may be modified materially without departing from the spirit of my invention. For example, the liquid to be treated may be supplied to the treatment chamber at a position above the central portion of the diaphragm 9, and may be withdrawn therefrom at a position adjacent the periphery of the diaphragm. The points of inflow and outflow of liquid should, in any case, be spaced from one another and so positioned with respect to the region of intense high frequency compressional waves as to cause all the liquid to pass through that region. With this end in view, either the liquid inlet or liquid outlet passage should communicate with the interior of the treatment chamber at a position within said region, and one of said passages should preferably communicate therewith at a position of intense compressional waves. Since the intensity of the compressional waves is greatest in the region above the central portion of the diaphragm and the piezo-electric generator, and since the liquid tends to build up toward a relatively narrow apex in this region, I prefer, for the best results, to use the arrangement shown, in which the liquid outlet communicates with the body of liquid within the upper portion of this central region.

Furthermore, the apparatus may be modified, if necessary, for treatment of gaseous materials. For such use, the opening 61 may be closed or may be omitted entirely, and the receiving chamber 57 may also be dispensed with, the gas to be treated being continually introduced through inlet passage 54 and continually withdrawn through outlet passage 56. Treatment of gases in this manner may be employed, for example, for the purpose of influencing chemical reactions therein, or for sterilization thereof. The continuous treatment method may also be employed to produce either physical or chemical changes of various kinds in disperse systems comprising solid material dispersed in either a gas or liquid, or liquid material dispersed in a gas, or a gas dispersed in a liquid, or in general, any operation involving the action of high frequency compressional waves on fluid material.

It is also to be understood that the method and apparatus described for continuous treatment of fluids by high frequency compressional waves are not restricted to use with such waves produced by piezo-electric generating means, but may be employed with other forms of generating means, such as magneto-striction generators in which the high frequency compressional waves are produced by rapid changes in length of a metal bar or tube having magnetic properties in a high frequency magnetic field. Similarly, it is to be understood that the piezo-electric generating method and apparatus above described may be employed for producing high frequency compressional waves for other purposes than for the treatment of fluids.

Furthermore, it is to be understood that certain novel features of the invention may be employed independently of other features. For example, the above-described means for mounting the piezo-electric generator including the electrodes and the crystal means interposed therebetween, the circulation and cooling of the dielectric liquid medium, and the maintaining of said liquid medium in swirling motion around said piezo-electric generator, for the purposes above set forth, are not limited to use in conjunction with a plurality of crystals in series, but may also advantageously be employed with a piezo-electric generator comprising a single crystal.

The method and apparatus for producing high frequency compressional waves disclosed herein are disclosed and claimed in my divisional application Serial No. 196,223, filed March 16, 1938.

I claim:

1. The method of subjecting fluid material to treatment by high frequency compressional waves which comprises maintaining a high frequency electric field through a plurality of piezo-electric crystals having different resonant frequencies and arranged in series, at substantially the resonant frequency of one of said crystals, so as to produce alternate expansion and contraction of said one crystal without shattering, due to the damping action of another of said crystals; utilizing said alternate expansion and contraction to produce high frequency compressional waves in a fluid medium; transmitting said compressional waves through said fluid medium and through a diaphragm into a body of a different fluid maintained separate from said fluid medium and at the opposite side of said diaphragm, to produce a high frequency compressional wave system in said different fluid, and continually supplying said different fluid to said body and withdrawing said fluid therefrom in such manner as to cause all of said fluid to pass through said wave system.

2. The method as set forth in claim 1, in which said different fluid is continually withdrawn from the fluid body at a position spaced from said diaphragm and at the central portion of said wave system.

3. The method of subjecting fluid material to treatment by high frequency compressional waves which comprises maintaining a high frequency electric field through a plurality of separate piezo-electric crystals having different resonant frequencies and in series, at substantially the resonant frequency of one of said crystals, so as to produce alternate expansion and contraction of said one crystal at said frequency while damping said expansion and contraction by the other crystal or crystals to prevent shattering of said one crystal; maintaining a fluid medium in a position subject to movement of said one crystal so as to produce high frequency compressional waves in said medium; transmitting said compressional waves through said fluid medium and through a diaphragm into a separate body of a different fluid maintained at the opposite side of said diaphragm, to produce a high frequency compressional wave system in said last-named fluid; and continually supplying said last-named fluid to said body and withdrawing said fluid therefrom in such manner as to cause all of said fluid to pass through said wave system.

4. The method of subjecting fluid material to treatment by high frequency compressional waves which comprises maintaining a high frequency electric field through a piezo-electric crystal generator to produce high frequency vibrations therein; circulating a dielectric liquid around said generator in position to receive vibrations produced therein and thus produce high frequency compressional waves in said liquid at said position, while maintaining active swirling motion of said liquid around said generator to entrain and carry away gas evolved from said liquid by the action of said high frequency compressional waves; transmitting said compressional waves through a diaphragm into a separate body of fluid maintained at the opposite side of said diaphragm, to produce a high frequency compressional wave system in said last-named fluid; and continually supplying fluid to said body and withdrawing fluid therefrom in such manner as to cause all of said fluid to pass through said wave system.

5. An apparatus for use in the treatment of fluids by high frequency compressional waves comprising a receptacle provided at the lower end with a diaphragm and also provided with inlet passage means and outlet passage means communicating with the interior of said receptacle at positions spaced from one another for maintaining a body of fluid in a treatment region within said receptacle above said diaphragm; means for continually introducing fluid through said inlet passage means and continually withdrawing fluid through said outlet passage means; a housing providing an enclosed chamber below said diaphragm; a piezo-electric generator within said chamber; means for supplying high frequency electric current to said generator; a body of dielectric liquid within said chamber and around said generator and in position to transmit high frequency compressional waves from said generator to said diaphragm; and means for circulating said dielectric liquid within said chamber in such manner as to maintain active swirling movement of said liquid around said generator, including a tangentially directed inlet for said dielectric liquid adjacent said generator and an outlet for said liquid and gas entrained therein, said outlet opening into the upper portion of said chamber immediately below said diaphragm.

6. The method of subjecting a liquid material to treatment by high frequency compressional waves, which comprises: maintaining a high frequency electric field across a piezo-electric gen-

erator to produce high frequency compressional waves; transmitting such compressional waves through a fluid medium to a diaphragm spaced above said generator to cause vibration of said diaphragm at high frequency; maintaining a body of liquid material above said diaphragm and producing high frequency compressional waves in said liquid material by the vibration of said diaphragm and thereby causing said liquid material to assume a general conical shape above said diaphragm due to the action of said compressional waves; and continually supplying liquid to and removing liquid from said body in such manner as to cause all of said liquid to pass through the upper restricted portion of said conical body.

7. The method set forth in claim 6, said liquid being supplied to said body at a position within the lower outer portion thereof and being removed from said body at a position within the upper central portion thereof.

8. In a device for subjecting fluids to the action of high frequency compressional waves, including a treatment chamber and a generator chamber separated therefrom by a diaphragm located at the bottom of said treatment chamber, a piezo-electric generator located within said generator chamber and comprising: a lower supporting electrode having an upper surface located below said diaphragm; an upper electrode located between said diaphragm and said upper surface of said supporting electrode; a plurality of piezo-electric crystal plates having different resonant frequencies, located between said electrodes and positioned one above the other and in contact with one another; means connected to said electrodes for maintaining a high frequency electric field between said electrodes and through said crystals in series, substantially at the resonant frequency of one of said crystals; and a body of dielectric fluid within said generator chamber with a portion of said fluid disposed between said upper electrode and said diaphragm.

9. An apparatus for use in the treatment of fluids by high frequency compressional waves comprising a receptacle provided at the lower end with a diaphragm and also provided with inlet passage means and outlet passage means communicating with the interior of said receptacle at positions spaced from one another for maintaining a body of fluid in a treatment region within said receptacle above said diaphragm, one of said passages opening into said receptacle at a position above, and spaced from, the central portion of said diaphragm; means for continually introducing fluid through said inlet passage means and continually withdrawing fluid through said outlet passage means; a housing providing an enclosed chamber below said diaphragm; a piezo-electric generator within said chamber; means for supplying high frequency electric current to said generator; and a body of dielectric liquid within said chamber and around said generator and in position to transmit high frequency compressional waves from said generator to said diaphragm.

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