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J. B. JONES
APPARATUS FOR GENERATING ULTRASONIC
ENERGY OF HIGH INTENSITY

2,855,526

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2 Sheets-Sheet 1

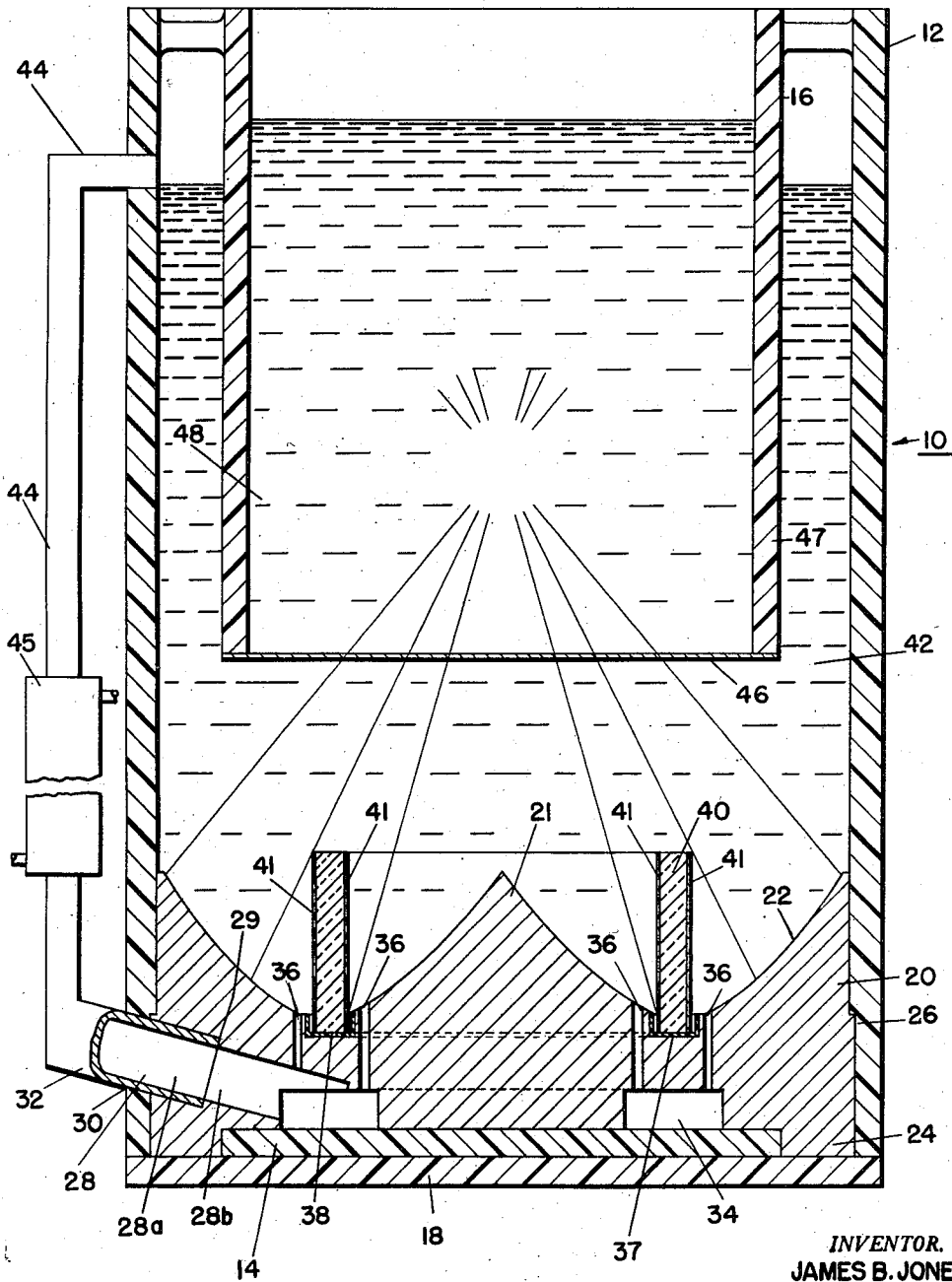


Fig. 1

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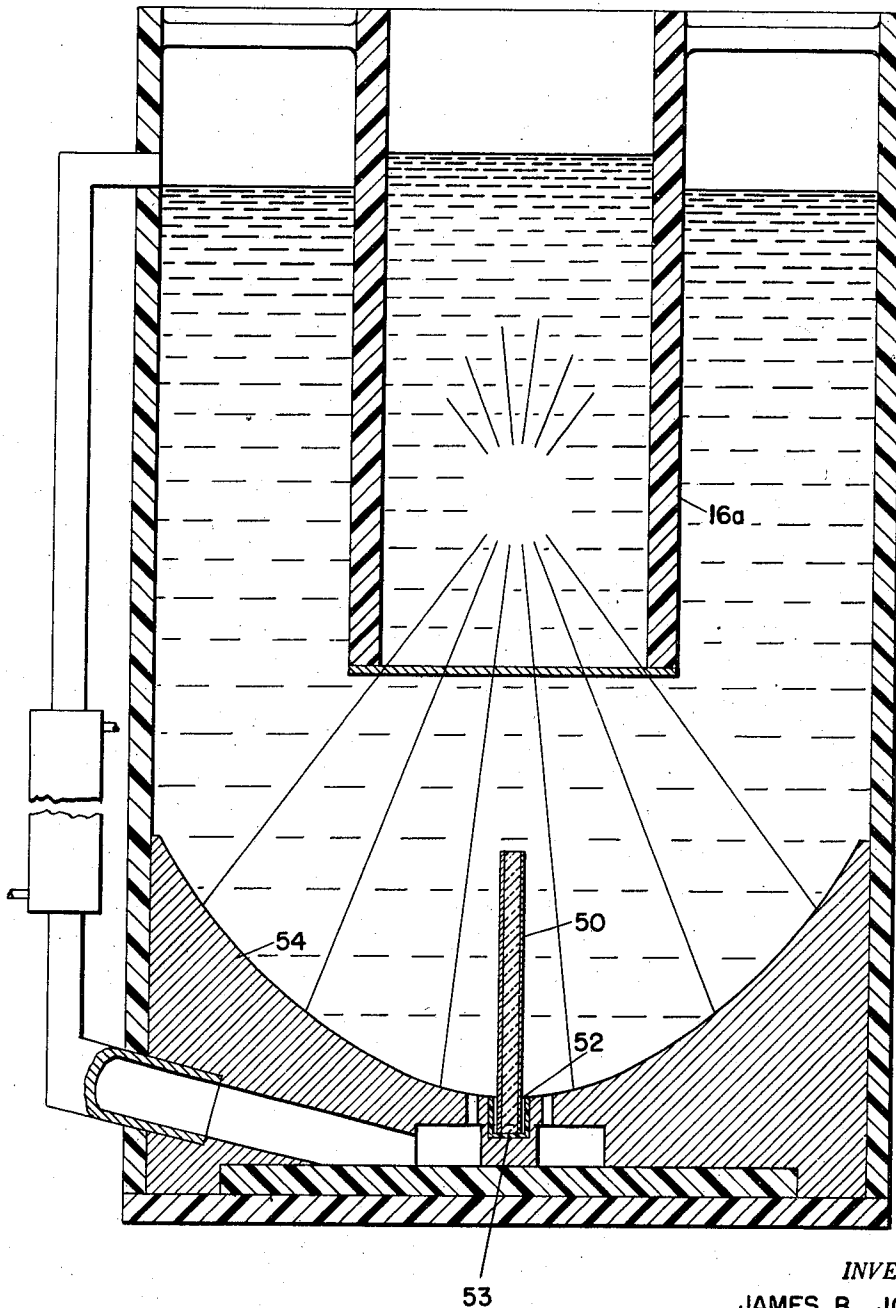


Fig. 2

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APPARATUS FOR GENERATING ULTRASONIC ENERGY OF HIGH INTENSITY

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9 Claims. (Cl. 310—8.5)

The present invention relates to apparatus for generating ultrasonic energy of high intensity, and more particularly, to an electro-acoustic transducer apparatus capable of simultaneously both generating ultrasonic energy and focusing such energy to a high intensity level.

It has long proved desirable to obtain ultrasonic energy having a high intensity. Thus, many ultrasonic phenomena cannot be achieved except at a high energy level. Suggested prior methods for concentrating ultrasonic energy have included the use of converging lenses, such as converging lenses of methyl methacrylate, and the use of concave transducers.

To a large extent these prior methods have not proven satisfactory for a variety of reasons. Thus, refraction systems have not proved satisfactory because of low efficiency at high power levels, and because the most satisfactory materials from the impedance-matching standpoint deteriorate at high power levels. The use of energy having a high intensity has proven impractical with concave transducers, because they are costly and because of overheating in the region of the transducer source. Such overheating leads to depolarization of certain transducer materials, such as barium titanate, and other adverse effects on the transducer.

Liquids which will adequately transmit acoustic energy will cavitate if the acoustical energy level is sufficiently high. The presence of cavitation bubbles impedes the transmission of acoustical energy and therefore provides substantial inefficiency. It is desirable, therefore, that the acoustical energy level in a liquid which constitutes an acoustical transmission medium be below the threshold level of cavitation in that liquid. The liquid adjacent to the transducer must therefore conduct the acoustical energy away from the transducer with minimum loss and also act as a coolant for the transducer.

It is ordinarily accepted that optimum transmission into a liquid occurs when one side of the transducer is air-backed and therefore transmits very little energy into the air backing. The air backing, however, does not conduct heat away from the transducer, so that all the heat must be carried away on the power delivery side. Modern transducing materials, such as barium titanate, suffer from the weakness that the temperature of the material must not exceed the Curie temperature if remnant polarization is to remain and separate polarization excitation avoided.

In recent years the use of piezo-electric ceramics, such as barium titanate, has to an appreciable degree displaced the use of natural piezo-electric materials, such as quartz crystals, as piezo-electric generators of ultrasonic energy. Such piezo-electric ceramics can be molded into a great variety of shapes and polarized after molding. Moreover, barium titanate has the further marked advantage over quartz in that lower applied voltages can be used to effect excitation. This permits the use of safer electrical equipment, and considerably reduces insulation problems in constructing a transducer.

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The present invention has as an object the provision of apparatus in which ultrasonic energy of high intensity can be obtained within a relatively small region.

The present invention has as another object the provision of apparatus in which ultrasonic energy of high intensity can be transmitted for protracted periods without adverse effect upon the transducer.

It is a further object of the present invention to provide an apparatus for generating ultrasonic energy of high intensity utilizing a piezo-electric ceramic transducer in which close temperature control of the piezo-electric ceramic is achieved.

It is a still further object of the present invention to provide an apparatus for generating ultrasonic energy of high intensity in which a piezo-electric ceramic is utilized as the transducer, and in which energy-dissipating cavitation effects in the transmitting medium proximate the transducer are avoided.

These and other objects are accomplished by the apparatus of the present invention in which a transducer is positioned within reflecting surfaces having a high impedance mismatch with the transmitting liquid and capable of reflecting and focusing the energy developed by the transducer to a small focal region. Disposed around the transducer is a liquid coupling medium having very low electrical conductivity, a relatively high boiling point, a relatively low vapor pressure, and a relatively minor amount of dissolved gas therein. A separate container for the liquid being treated is provided at a spaced distance above the reflecting surface so that the focal region of the reflecting surface is within such separate container. Means are also provided in the apparatus of the present invention for circulating the liquid coupling medium, preferably with heat exchange, so as to provide maximum heat dissipation for the surfaces of the transducer.

For the purpose of illustrating the invention there are shown in the drawings forms which are presently preferred; it being understood, however, that this invention is not limited to the precise arrangements and instrumentalities shown.

Figure 1 discloses a vertical section through one embodiment of the apparatus of the present invention.

Figure 2 discloses a vertical section through another embodiment of the apparatus of the present invention.

Referring initially to Figure 1, the apparatus of the present invention is designated 10 and includes an outer vessel 12 which may be of transparent plastic, such as transparent methyl methacrylate. The bottom or floor 18 of vessel 12 is provided with a raised centrally-positioned circular platform 14 having a thickness somewhat greater than the wall thickness of the remainder of vessel 12. An inner vessel 16 which may be made of similar transparent plastic material is suspended within vessel 12 at a regulated spaced distance from the floor 18 of vessel 12.

A curved reflector constructed and arranged to have a high specific impedance mismatch with the transmitting liquid and designated generally as 20 is provided within vessel 12. Reflector 20 is formed of metal having for an uppermost surface a smoothly finished curved reflecting surface 22 having a centrally positioned apical portion 21. The outer portion of the underside of curved reflector 20 is provided with an outwardly and downwardly extending annular flange member 24 which nests adjacent circular platform 14 and within recess 26 provided in the wall of vessel 12. Vessel 12 is somewhat resilient permitting the anchorage of curved reflector 20 above floor 18 as set forth above.

Curved reflector 20 is provided with a telescopic circularly cross-sectioned inlet 28, having a large diametered

section 28a and a small diametered section 28b separated by shoulder 29. The section 28a may be mated with a mating opening 30 in the wall of vessel 12. A section of tubing or other conduit 32 may be inserted through mating opening 30 into inlet section 28a with the outer wall surface of the tubing 32 forming a tight seal with the inner surface of opening 30 and of section 28a. Inlet 28 extends into curved reflector 20 and joins an annular plenum or manifold conduit chamber 34 which is provided with a double row of closely spaced riser conduits 36 which discharge into the interior of vessel 12. The upper surface of curved reflector 20 is further furnished with an annular seating groove 37 provided with an insulator liner 38, such as a liner of phenolformaldehyde laminated plastic, intermediate the rows of riser conduits upon which a molded barium titanate transducer ring 40 is seated. As will be more fully explained below the oil discharged from riser conduits 36 scrubs both sides of transducer ring 40. Barium titanate transducer ring 40 may be coupled to sources of electrical energy in a conventional manner.

The inner and outer wall surfaces of transducer ring 40 are coated with a thin coating or film 41 of elemental silver, so that transducer ring 40 is in effect a condenser; with the barium titanate portion forming the dielectric and the silver films 41 forming the electrodes.

Disposed above curved reflector 20 is a pool of oil 42, preferably a pool of transformer oil or like stable hydrocarbon oil having a relatively low vapor pressure, and not containing an appreciable amount of dissolved gases. Oil 42 forms a liquid coupling medium for the transmission of acoustic energy from transducer 40 to within vessel 16, as will be more fully explained hereinbelow.

A discharge duct 44 for vessel 12 is provided in wall 12 appreciably above the floor 46 of inner vessel 16. Discharge duct 44 is connected to heat exchanger 45 shown diagrammatically to the left of vessel 12. Liquid from duct 44 may be cooled in heat exchanger 45 and then conveyed to duct 32.

Inner vessel 16 is, as heretofore noted, fixedly suspended a spaced distance above floor 18 (and reflector 20) in vessel 12. The distance between floor 18 and the floor 46 of inner vessel 16 is critical, as it is essential for the purposes of the present invention that inner vessel 16 be so suspended that the focal zone of the curved reflector 20 be within the vessel 16, somewhat above the floor 46 thereof. The floor 46 of inner vessel 16 should be membranous, such as a thin polyester resin film, having a thickness of but a minor fraction of the thickness of the wall portion 47 thereof, and preferably as thin as possible.

Inner vessel 16 may be provided with means for circulating the liquid therethrough so that the process of the present invention may be effected on a continuous basis.

The foregoing arrangement permits a liquid or emulsion 48 in inner vessel 16 to undergo treatment with ultrasonic energy of high intensity reflected from reflector 20. The liquid 48, unlike transformer oil 42 may be, and preferably is, readily cavitated on exposure to ultrasonic energy.

The operation of the apparatus of the present invention is as follows:

The liquid 48 to be treated is placed within inner vessel 16, and is then exposed to the action of the ultrasonic energy generated by barium titanate transducer 40. Such ultrasonic energy is focused by means of reflector surface 22 to a small region within inner vessel 16. While barium titanate transducer 40 is generating ultrasonic energy, or during the time interval intermediate the generation of ultrasonic energy, liquid 42 is circulated through outer vessel 12 through inlet 28, plenum chamber 34, riser conduits 36, and outlet 44. The passage of liquid through the double row of riser conduits 36 ensures the cooling and scrubbing of both faces of barium titanate transducer 40. Such circulated liquid 42 is cooled by heat exchange in heat exchanger 45 removing heat developed by barium titanate transducer 40 away from transducer 40, so that

transducer 40 is not adversely affected by such heat. Accurate temperature control may be maintained so that transducer 40 generates energy at a constant temperature level, permitting closely reproducible results to be achieved. Moreover, temperature control of the liquid 48 being treated within inner vessel 16 may be effected.

Furthermore, erosion of transducer 40 by the cavitation action of liquid 42 proximate thereto is minimized as the energy delivered to the coupling medium liquid 42 is dispensed along both sides of the transducer ring 40, so that while energy of high intensity is delivered to inner vessel 16, the unit intensity of energy from the transducer side surface is relatively low. This permits a liquid 48 which would be readily cavitated proximate a barium titanate transducer with resultant erosion of the barium titanate transducer 40 to be treated with acoustic energy of high intensity.

Example

Utilizing a transformer oil for the liquid coupling medium 42, a photographic emulsion comprising a mixture of about 10 weight percent gelatin and 10 weight percent of silver halide was effectively treated with ultrasonic energy having a frequency of 800 kilocycles per second, and an intensity of 115 watts per square centimeter along the plane passing through the focal zone of curved reflector 20 within inner vessel 16. The ultrasonic energy was pulsed for ten seconds on and ten seconds off. Under the aforesaid conditions, no erosion of barium titanate transducer 40 due to cavitation in the oil coupling medium 42 was encountered, and the ultrasonic energy per unit volume within the focal zone of curved reflector 20 was closely maintained at the aforesaid level.

In the embodiment shown in Figure 2 the construction is substantially the same as that shown in Figure 1 except that in place of an annular transducer 40 and a curved reflector having a peak 21, a plate-like transducer 50 is loosely positioned in a groove 52 provided with an insulator liner 53 at the base of a single cavity curved reflector 54. The transducer 50 generates energy from both of its faces which energy is focused by reflector 54 into a focal zone within inner vessel 16a.

The present invention may be embodied in other specific forms without departing from the spirit or essential attributes thereof, and accordingly, reference should be made to the appended claims, rather than to the foregoing specification as indicating the scope of the invention.

I claim:

1. Apparatus for effecting ultrasonic treatment comprising a relatively large vessel, a curved reflector disposed within said relatively large vessel, said reflector having a focal zone within said relatively large vessel spaced at a distance from the upper surface thereof, an annular transducer for generating ultrasonic wave energy disposed within the curve of said reflector, said transducer comprising a piezoelectric material having a plurality of spaced electroded surfaces facing the curved upper surface of said reflector, each of said electroded surfaces radiating the ultrasonic energy generated by said transducer, a second relatively small vessel suspended within the relatively large vessel and spaced a distance above the upper face of said reflector such that the focal zone of said reflector is within the interior of said relatively small vessel, inlet means in said relatively large vessel for permitting the introduction of liquid thereto, and outlet means in said relatively large vessel for permitting the exit of liquid therefrom.

2. Apparatus for effecting ultrasonic treatment comprising a relatively large vessel, a curved reflector disposed within said relatively large vessel, said reflector having a focal zone within said relatively large vessel spaced at a distance from the upper surface thereof, a transducer for generating ultrasonic wave energy disposed within the curve of said reflector, said transducer

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comprising a piezoelectric material having a plurality of spaced electroded surfaces facing the curved upper surface of said reflector, each of said electroded surfaces radiating the ultrasonic energy generated by said transducer, a second relatively small vessel suspended within the relatively large vessel and spaced a distance above the upper face of said reflector such that the focal zone of said reflector is within the interior of said relatively small vessel, inlet means in said relatively large vessel for permitting the introduction of liquid thereto, and outlet means in said relatively large vessel for permitting the exit of liquid therefrom.

3. Apparatus for effecting ultrasonic treatment comprising a relatively large vessel, a curved reflector disposed within said relatively large vessel, said reflector having a focal zone within said relatively large vessel spaced at a distance from the upper surface thereof, a transducer for generating ultrasonic wave energy disposed within the curve of said reflector, said transducer comprising a piezoelectric material having a plurality of spaced electroded surfaces facing the curved upper surface of said reflector, each of said electroded surfaces radiating the ultrasonic energy generated by said transducer, a second relatively small vessel suspended within the relatively large vessel and spaced a distance above the upper face of said reflector such that the focal zone of said reflector is within the interior of said relatively small vessel, inlet means in said relatively large vessel for permitting the introduction of liquid thereto, a conduit for liquid within said reflector, said conduit being in liquid communication with said inlet means, discharge orifices in communication with said conduit at the upper surface of said reflector discharging proximate both faces of the transducer, and outlet means in said relatively large vessel for permitting the exit of liquid therefrom.

4. Apparatus for effecting ultrasonic treatment comprising a relatively large vessel, a curved reflector disposed within said relatively large vessel, said reflector having a focal zone within said relatively large vessel spaced at a distance from the upper surface thereof, a plate-shaped transducer for generating ultrasonic wave energy disposed within the curve of said reflector, said transducer comprising a piezoelectric material having a plurality of spaced electroded surfaces facing the curved upper surface of said reflector, each of said electroded surfaces radiating the ultrasonic energy generated by said transducer, a second relatively small vessel suspended within the relatively large vessel and spaced a distance above the upper face of said reflector such that the focal zone of said reflector is within the interior of said relatively small vessel, inlet means in said relatively large vessel for permitting the introduction of liquid thereto, and outlet means in said relatively large vessel for permitting the exit of liquid therefrom.

5. Apparatus for effecting ultrasonic treatment comprising a relatively large vessel, a curved reflector disposed within said relatively large vessel, said reflector having a focal zone within said relatively large vessel spaced at a distance from the upper surface thereof, an annular transducer for generating ultrasonic wave energy disposed within the curve of said reflector, said transducer comprising a piezoelectric material having a plurality of spaced electroded surfaces facing the curved upper surface of said reflector, each of said electroded surfaces radiating the ultrasonic energy generated by said transducer, and a second relatively small vessel suspended within the relatively large vessel and spaced a distance above the upper face of said reflector such that the focal zone of said reflector is within the interior of said relatively small vessel.

6. Apparatus for effecting ultrasonic treatment comprising a relatively large vessel, a curved reflector disposed within said relatively large vessel, said reflector having a focal zone within said relatively large vessel spaced at a distance from the upper surface thereof, a

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transducer for generating ultrasonic wave energy disposed within the curve of said reflector, said transducer comprising a piezoelectric material having a plurality of spaced electroded surfaces facing the curved upper surface of said reflector, each of said electroded surfaces radiating the ultrasonic energy generated by said transducer, a second relatively small vessel suspended within the relatively large vessel and spaced a distance above the upper face of said reflector such that the focal zone of said reflector is within the interior of said relatively small vessel, a liquid coupling medium intermediate said reflector and the floor of the relatively small vessel consisting of a liquid which resists cavitation, inlet means in said relatively large vessel for permitting the introduction of liquid medium thereto, and outlet means in said relatively large vessel for permitting the exit of liquid medium therefrom.

7. Apparatus for effecting ultrasonic treatment comprising a relatively large vessel, a curved reflector disposed within said relatively large vessel, said reflector having a focal zone within said relatively large vessel spaced at a distance from the upper surface thereof, a transducer for generating ultrasonic wave energy disposed within the curve of said reflector, said transducer comprising a piezoelectric material having a plurality of spaced electroded surfaces facing the curved upper surface of said reflector, each of said electroded surfaces radiating the ultrasonic energy generated by said transducer, a second relatively small vessel suspended within the relatively large vessel and spaced a distance above the upper face of said reflector such that the focal zone of said reflector is within the interior of said relatively small vessel, inlet means in said relatively large vessel for permitting the introduction of liquid thereto, a conduit for liquid within said reflector, said conduit being in liquid communication with said inlet means, discharge orifices in communication with said conduit at the upper surface of said reflector discharging proximate both faces of the transducer, outlet means in said relatively large vessel for permitting the exit of liquid therefrom, said outlet means being joined to said inlet means by a duct containing means for cooling liquid passed therethrough.

8. Apparatus for effecting ultrasonic treatment comprising a relatively large vessel, a curved reflector disposed within said relatively large vessel, said reflector having a focal zone within said relatively large vessel spaced at a distance from the upper surface thereof, an annular barium titanate transducer for generating ultrasonic wave energy seated within a groove on the upper face of said reflector, said transducer comprising a piezoelectric material having a plurality of spaced electroded surfaces facing the curved upper surface of said reflector, each of said electroded surfaces radiating the ultrasonic energy generated by said transducer, a second relatively small vessel suspended within the relatively large vessel and spaced a distance above the upper face of said reflector such that the focal point of said reflector is within the interior of said relatively small vessel, inlet means in said relatively large vessel for permitting the introduction of liquid thereto, a conduit being in liquid communication with said inlet means, discharge orifices in communication with said conduit at the upper surface of said reflector and discharging proximate both sides of the inner and outer faces of the transducer, outlet means in said relatively large vessel for permitting the exit of liquid therefrom, said outlet means being joined to said inlet means by a duct containing means for cooling liquid passed therethrough.

9. Apparatus for effecting ultrasonic treatment comprising curved acoustically reflecting means, electromechanical transducer means for generating ultrasonic wave energy disposed within the curve of said acoustically reflecting means, said reflecting means directing the ultrasonic wave energy from said transducer means towards a focal region within said apparatus of small volume,

whereby said focal region has a high acoustical energy level, a solid acoustic energy transmitting barrier remote from said reflecting means and intermediate said transducer means and said focal region, liquid acoustic transmission means intermediate said reflecting means and said barrier, and means for cooling said liquid acoustic transmission means.

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