HIGH FREQUENCY ULTRASONIC FOG GENERATOR AND METHOD

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ABSTRACT OF THE DISCLOSURE

A high frequency ultrasonic fog generator having a liquid chamber containing the liquid to be formed into a fog, transducer means associated with the liquid chamber for agitating the liquid therein with ultrasonic energy to form a geyser, means for introducing gas into the liquid chamber such that swirlings and directional changes are imparted to the fog, a cover on the liquid chamber having at least one opening therein communicating from the exterior of the liquid chamber to the interior thereof, the opening being employed to emit a mist of the liquid from the liquid chamber, means for causing the large droplets in the geyser to drop back into the liquid in the liquid chamber.

The invention relates to ultrasonic fog generators and, in particular, to such fog generators wherein the fog is generated in a chamber and is entrained from the chamber into the surrounding atmosphere.

Ultrasonic fog generators of the invention are most generally utilized for medical treatment purposes. For some treatments, the moisture in the air to be breathed should be made available to the patient in the smallest possible droplets. For other treatments, the droplets should be somewhat larger.

Up to now, it has been quite difficult to emit only the very small droplets, obtained from the liquid, into the surrounding atmosphere. In order to utilize only the very small droplets, it is necessary to remove the larger droplets from the geyser which is developed in the chamber. The geyser is made up of droplets of the liquid and is formed by irradiating the liquid with enough acoustic power by means of an ultrasonic transducer operating, preferably, in the frequency range of 600 kHz to 1 MHz.

The transducer is positioned in the base of the liquid chamber and is, preferably, a flat disk which is vibrated in its thickness mode. Most commonly, these disk transducers are formed of barium titanate, barium cobalt titanate, barium strontium titanate, barium lead titanate, other metallic titanates, or in various combinations with or without other additives. The particular transducer material used are dictated by the various operating parameters and are determined in a manner well-known in the transducer art. Nonetheless, other types of ultrasonic transducers, which are capable of being mounted in the base of the chamber and of producing ultrasonic vibrations of the proper frequency and of sufficient power, may also be used.

The disk transducer vibrates the liquid, which directly overlaps it, and causes a geyser to form above the transducer. This geyser is made up of small droplets which are formed by the disintegration of the liquid subjected to intense, internal, acoustic turbulence by the ultrasonic field. The diameter of the bulk of the droplets in the geyser is in the range between 0.01 and 100 microns. The acoustic energy in the liquid radiates upward from the center of the transducer in the shape of a cone. For this reason, the flat transducer possesses one principal advantage over a focusing transducer. The energy from a focusing transducer is concentrated at the focus and if the level of the liquid in the chamber is not above the focus, there will not be enough transfer of acoustical energy to the liquid.

To form a usable geyser for use as a fog generator for dispensing medication for inhalation, it is best, according to the present invention, to utilize a nonfocusing transducer, such as a flat disk, which produces direct ultrasonic excitation of the overlying liquid over a relatively broad area. This broad area constitutes about 25% of the surface area of the transducer.

It is an important object of the invention to provide a method of producing fog by ultrasonic excitation of the liquid.

It is also an object of the invention to provide such a method wherein the smaller droplets remain in the fog and the larger droplets are returned to the liquid source.

It is a further object of the invention to provide apparatus for producing fog by ultrasonic excitation of the liquid source.

It is a still further object of the invention to provide apparatus wherein only the smaller droplets are emitted into the surrounding atmosphere.

It is a still further object of the invention to provide such apparatus wherein the gas is introduced near the wall of the chamber in which the geyser is being formed is maintained at a predetermined level.

It is another object of the invention to provide such apparatus wherein a gas is introduced into the chamber at a pressure above the ambient pressure.

It is still another object of the invention to provide such apparatus wherein the gas is introduced through the top of the chamber.

It is a still further object of the invention to provide such apparatus wherein the gas is introduced near the wall of the chamber and in a direction such that it swirls within the chamber to cause the larger droplets to fall back under centrifugal forces into the pool of liquid.

These and other objects, features, advantages and uses will be apparent during the course of the following description, when taken in conjunction with the accompanying drawings, wherein:

FIGURE 1 is a perspective view of an ultrasonic fog generator of the invention, showing the units enclosed in their cabinets, ready to be connected together and to the A-C mains;

FIGURE 2 is an enlarged, horizontal, sectional view, taken on the lines 2--2 of FIGURE 1, viewed in the direction of the arrows;

FIGURE 3 is an enlarged, vertical, sectional view, taken on the lines 3--3 of FIGURE 1, viewed in the direction of the arrows;

FIGURE 4 is a horizontal, sectional view, taken on the lines 4--4 of FIGURE 3, viewed in the direction of the arrows;

FIGURE 5 is a vertical, sectional view, taken on the lines 5--5 of FIGURE 2, viewed in the direction of the arrows;

FIGURE 6 is a horizontal, sectional view, taken on the lines 6--6 of FIGURE 5, viewed in the direction of the arrows;

FIGURE 7 is an enlarged, vertical, sectional view, taken on the lines 7--7 of FIGURE 6, viewed in the direction of the arrows;

FIGURE 8 is an enlarged, vertical, sectional view, taken on the lines 8--8 of FIGURE 3, viewed in the direction of the arrows;

FIGURE 9 is a horizontal, plan view of an alternative embodiment of the top which may be used with the liquid chamber of FIGURES 1 through 8;
FIGURE 10 is a vertical, elevational view of the top of FIGURE 9, viewed in the direction of arrow 10 of FIGURE 9.

FIGURE 11 is an alternative embodiment of ultrasonic fog generator of the invention; and

FIGURE 12 is a vertical, sectional view, taken on the lines 12—12 of FIGURE 11, viewed in the direction of the arrows.

Cross-section 15, wherein for the purpose of illustration, are shown preferred embodiments of the ultrasonic fog generator of the invention, the numeral 20 designates a fog generator of the invention, generally. Fog generator 20 (FIGURE 1) is seen to comprise cabinets 22 and 24. Cabinet 22 contains the ultrasonic signal generator (details not shown) and cabinet 24 contains the liquid chamber, the liquid reservoir and the blower.

The ultrasonic signal generator is connected to the 115 volt A-C mains by means of cable 26 and to the blower and transducer by means of cable 28. The ultrasonic signal generator is of a type well-known in the art and any circuit may be used which will produce a signal of sufficient power at the nominal frequency of the order of 800 kHz. It should be understood, however, that the teachings of the invention apply within the range of about 500 kHz to about 1 MHz.

Line 29, which is contained in cable 28, supplies A-C power from the ultrasonic signal generator to the blower and line 30, which is also contained in cable 28, supplies the ultrasonic signal to the transducer. Switch 32 on the front panel of cabinet 22 is the master switch and it connects the A-C power to the contacts of timer 36, turns on the filaments of the vacuum tubes of the signal generator and the pilot light 38 and turns on the cooling fan which is mounted inside cabinet 22 (details not shown).

Timer 36 turns on the blower in cabinet 24 and applies high voltage to the vacuum tubes of the signal generator. Timer contact 34 is used to turn the signal generator to obtain maximum output (highest geyser) from the transducer. This adjustment is made with the assembly contained in cabinet 24 removed from the cabinet to permit viewing of the geyser when making the adjustment. After this has been done, the timer 34 is locked and the contents of cabinet 24 are slid back into the cabinet. Cabinet 24 is provided with handle 40 and knurled screws 42 to facilitate the removal of the assembly from the cabinet. In order to remove the assembly from the cabinet, it is necessary to lift pipe 44 from the assembly and out of the cabinet through opening 46.

The fog is emitted into the surrounding atmosphere through pipe 44 and the amount of liquid in the reservoir is viewed through opening 46 which is provided with an indicator to show the amount of liquid which must be added to the reservoir to bring it back to full capacity.

FIGURES 2 through 5 show the placement of the equipment within cabinet 24. It comprises liquid chamber 48, liquid reservoir 50 and blower 52. These components are mounted on plate 54 to which are attached plastic buttons 56 to facilitate sliding the assembly in and out of the cabinet. Connection from the ultrasonic signal generator to the transducer is made by means of plug 51 and receptacle 33 (FIGURES 2 and 3). A similar plug and receptacle are used at the signal generator. Cable 30 is brought into cabinet 24 through opening 58 in the rear thereof. A-C connection is made to the blower 52 by means of 35 as shown in FIGURES 2 and 3.

Liquid chamber 48 comprises top 60 which is preferably removable, wall 62, and base or bottom 64. Transducer 66, which is preferably of the ceramic type previously described, is mounted in base 64 as shown in FIGURE 5. Transducer 66 is provided with two electrodes 68 and 70 applied to the opposite faces of the disk. Electrode 68 completely covers one face of the transducer, its edges and the peripheral portion of the second face. Electrode 70 is applied to the second face of transducer 66 such that there is an unelectroded ring portion 72 between electrode 70 and the portion of electrode 68 on the second face of the transducer.

Springs 74 are connected to the electrodes and to conductive pads 75 (FIGURE 7) which are mounted on strut 90 so as to be insulated from each other. Connection is made to connector 33 by means of leads 81 and wires 82 as shown in FIGURE 6. When an ultrasonic excitation signal of the proper frequency is applied to transducer 66 through these connections, the transducer vibrates in thickness mode and forms a geyser 84 from the liquid 86 as shown in FIGURE 5.

The liquid 86 is kept at the proper level by means of valve 88 which is located between reservoir 50 and chamber 48. Valve 88 is a two position valve; in one position, it closes channel 90 and thereby inhibits the flow of liquid from the reservoir 50 to the chamber 48 and in the other position, it opens channel 90 and thereby permits liquid to flow from reservoir 50 to chamber 48. The position of valve 88 is controlled by means of knob 93.

It should be noted that chamber 48 may be easily disconnected from channel 90. This is possible because channel 90 is connected to chamber 48 by means of a force-fitting taper as shown in FIGURES 3-5. This enables the user to disconnect the chamber and place it, for example, in an autoclave for sterilization.

Reservoir 50 is filled to the correct level, as shown on the indicator, through opening 91 with valve 88 closed. When the correct level is reached, cap 99 is threaded snugly over opening 91 providing an airtight seal to produce a partial vacuum above the liquid in the reservoir as its level diminishes. Now, fill chamber 48 to a level that covers the inlet from the reservoir 50 to the midpoint of channel 90. Open valve 88 and henceforth, as the liquid in the chamber is consumed, it will be replenished from the reservoir.

Usually, one can obtain the same result, by filling reservoir 50 and then opening valve 88. In either case, operation will continue if the surface tension and viscosity of the liquid were broken initially. The surface tension may also be broken, under certain conditions, by using a wetting agent in the liquid. However, the wetting agent must be compatible with the solution and the treatment procedure.

Since, as a general rule, small moisture droplets are best for the treatment of most respiratory ailments, it is advisable to avoid, insofar as is possible, the emission of large droplets into the surrounding atmosphere. This is accomplished by causing the liquid droplets to precipitate or fall back into the liquid source or to collect in the exit conduit prior to emission into the surrounding atmosphere. Top 60 of chamber 48 is removable and is provided with a pair of conduits of noncorrosive plastic such as polycarbonate or similar material. These conduits 92 and 94 are respectively utilized to supply gas, such as air, to the chamber at a pressure above ambient pressure, and to entrain the liquid mist (fog) into the surrounding atmosphere.

As can be seen from the figures, conduits 92 and 94 lead from the inside to the outside of the chamber through suitable openings in top 60. While the gas utilized in the embodiment of the invention, illustrated and described, is air, it is also within the contemplation of the invention to use other gases for medical purposes. Moreover, one may use a pressure tank or other device for delivering the gas connected to the chamber in lieu of the blower shown and described.

Flexible hose 96 is connected between blower output 98 and conduit 92 so that the air is delivered to chamber 48 close to its wall 62 so that the air swirls around the chamber in a direction away from the opening of conduit 94 within the chamber. As the air swirls in the chamber in the direction indicated by arrows 100, as shown in FIGURES 4 and 5, the liquid droplets forming the geyser 84 move first in the same direction as the airflow. But
when they reach the aperture of helicoid section 94A of tube 94 they are subjected to a sharp change in direction (nearly 340° upwards) which separates out the remaining large or medium size drops which have not been collected on the walls 62. After entering into conduit 94, which has a helicoidal shape 94A, there is a further centrifugation of the few large drops which may have escaped the two preceding separating steps (i.e. collection on walls 62 and change of direction as shown by arrows 102).

The theory underlying the production of fine drops containing small droplets is:

(1) The introduction of the gas into the chamber such that its motion is tangential to the walls, which causes centrifugation of the gaser and a dropping back of many of the larger droplets into the liquid pool (as shown by arrows 101).

(2) The remainder of the droplets in the fog must change direction by an angle of about 340° (as shown by arrows 102), against, among other forces, the force of gravity when the mist enters helicoidal section 94A of conduit 94. This causes many of the remaining larger droplets to separate from the flow of the balance of the mist and drop back into the liquid pool (as shown by arrows 103).

(3) Further centrifugation takes place in conduit 94 since the radius of the gas vortex has decreased due to its being confined in the conduit 94 and the larger droplets are deposited on the walls of helicoidal section 94A of conduit 94 (as shown by arrows 105). The droplets so collected drop back into the liquid pool because conduit 94 is tilted downward toward the opening of the conduit within the chamber.

The amount of airflow can be varied by adjusting damper 104 (FIGURES 3 and 8). Damper 104 is comprised of openings 106 and plate 108. Plate 108 is rotated by means of knob 110 so that it closes all but one, some, or none of the openings 106 in damper 104. When all but one of the openings are closed, air reaching the blower is considerably reduced and the air delivered by the blower is at a minimum. When all the openings are open, air is fed to the blower through the damper openings so that the air delivered by the blower is at a maximum.

Under certain conditions, a coarse mist (large droplets) is desired. In such cases, top 61 is substituted for top 60. Gas enters the chamber through conduit 95 and the mist is emitted to the surrounding atmosphere through conduit 97. Because very little of the conduit 97 projects into the chamber, the droplets separate by selective swirling stages within the chamber is minimal. Consequently, a large number of coarse droplets from the gaser is entrained in the conduit 97 and added through pipe 145 which is attached to conduit 97 when it is in operation. Operation for the production of mists of small droplets (using top 60) proceeds as follows: the screws 42 are loosened, pipe 44 is removed and the assembly is slid out of cabinet 24. Valve 88 is closed and cap 89 is removed from opening 91. Medicated solution is poured into reservoir 50 to the proper level and cap 89 is replaced. Medicated solution is now poured into chamber 48 to at least the midpoint of channel 90 and then valve 88 is opened. Next, switch 32 is turned on and after 60 seconds delay, timer 36 is turned on for 2 or 3 minutes. As soon as the gaser forms, trimmer 34 is adjusted for maximum gaser height and locked in place. Now, the timer is moved to the off position and switch 32 is turned off. The assembly is moved back into cabinet 24 and pipe 44 is put in place. Screws 42 are tightened and the fog generator is ready for treatment of patients.

Switch 32 is turned on. After 60 seconds' delay, the timer is moved to the setting for the desired treatment time and treatment begins. The system is designed so that if the timer is set for the maximum time permitted, it will turn off before the liquid in the reservoir is completely exhausted. This will prevent damage to the transducer and the signal generator.

In FIGURES 11 and 12, there is illustrated a further embodiment of ultrasonic fog generator of the invention. Fog generator 120 is seen to comprise liquid chamber 122, liquid reservoir 124, signal generator 126 and blower 128. Transducer 130 is similar to transducer 66 and is suitably connected to signal generator 126. When transducer 130 is excited, a gasser 132 is formed as shown in FIGURE 12. The gas such as is delivered to the chamber 122 by means of conduit 134 in the base of the chamber so that it enters the chamber close to wall 136. This causes the air to swirl in the chamber as shown by arrows 138.

The tangential flow of air causes an air vortex which subjects the gasser 132 to low frequency mechanical oscillation. This oscillation weakens the gasser's resistance to disintegration and increases the mist output. The large droplets are refluxed into the liquid pool as shown by arrows 140. The mist formed of the smaller droplets of gasser 132 move in the direction of arrows 142 out of conduit 144 which is flared within the chamber as shown at 146 for collecting large drops which then reflux into the liquid along the funnel walls.

The removal of the larger droplets from the mist formed by the gasser takes place in two steps:

(1) The gas is introduced into the chamber such that its motion is tangential to the walls, causing centrifugation of the gasser and a refluxing of many of the larger droplets back into the liquid pool as shown by arrows 148.

(2) Further centrifugation as shown by arrows 141 takes place in conduit 144 due to the constriction of the gas vortex within the conduit. This final centrifugation takes place because in a true vortex the product of the tangential velocity and the radius remains constant. Since the radius has been reduced drastically, the tangential velocity becomes very large thereby forcing the larger droplets against the walls of the conduit along which they run and then drop back into the liquid pool.

The reservoir 124 is filled by removing cap 148 and pouring the medicated solution through opening 150. The level in chamber 122 is maintained by means of float valve 153 which is connected to pipe 154 and operates in a manner well-known in the art. As the level lowers, the float drops, the valve opens and liquid flows through pipe 154 from reservoir 124 to chamber 122. When the liquid in the chamber reaches the desired level, the float valve closes and the flow of liquid from the reservoir to the chamber stops.

Controls similar to those used in the embodiment of FIGURES 1 through 10 may also be used for the operation of fog generator 120. Its operation is similar to that of the embodiment. Damper 149 is utilized to control the volume of air delivered to blower 128. Plate 151 is slid so that it covers none, some, or most of openings 152. If none are covered, the maximum amount of air is delivered by the blower. If most of them are covered, the minimum amount of air is delivered by the blower.

Operation of the apparatus of the invention and the carrying out of the method thereof are often improved if the gas is delivered to the liquid chamber at high velocity and thereby facilitates the initiation of the swirling motion within the liquid chamber.

While particular embodiments of the invention have been shown and described, it is apparent to those skilled in the art that modifications are possible without departing from the spirit and scope of the invention.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. An ultrasonic fog generator for entraining fogs produced from a liquid into the surrounding atmosphere comprising:
   an enclosed chamber for containing the liquid from which the fog is to be produced having a base, a top and a wall;
   at least one nonfocusing transducer mounted in the
8 a chamber for containing the liquid from which the fog is to be produced having a base, a top and a wall; at least one nonfocusing transducer mounted in the base of the chamber in direct contact with the liquid from which the fog is to be produced; means for applying ultrasonic excitation to the transducer such that when such excitation is applied to the transducer, a geyser is formed from the liquid within the chamber; the top of the chamber having two openings therein; means for introducing gas into the chamber at higher than ambient pressure and at high velocity through the first of the openings in the top thereof, said means for introducing gas into the chamber comprising: a pipe having two ends mounted in the first opening in the top of the chamber, one of the ends being inside the chamber, the other of the ends being outside the chamber; a portion of the pipe being inside the chamber, which portion is shaped such that the gas introduced into the chamber is caused to swirl therein; means connecting the end of the pipe outside the chamber to the blower; means in the second opening in the top of the chamber through which the fog is entrained into the surrounding atmosphere.

9. An ultrasonic fog generator for entraining fogs produced from a liquid into the surrounding atmosphere comprising: a chamber for containing the liquid from which the fog is to be produced having a base, a top and a wall; at least one nonfocusing transducer mounted in the base of the chamber in direct contact with the liquid from which the fog is to be produced; means for applying ultrasonic excitation to the transducer such that when such excitation is applied to the transducer, a geyser is formed from the liquid within the chamber; the top of the chamber having two openings therein; means for introducing gas into the chamber at higher than ambient pressure and at high velocity through the first of the openings in the top thereof; said means for introducing gas into the chamber comprising: a blower; a pipe having two ends mounted in the first opening in the top of the chamber, one of the ends being inside the chamber, the other of the ends being outside the chamber; a conduit projecting into the chamber through the opening in the top thereof through which the fog is dispersed into the surrounding atmosphere; the conduit having a smaller radius than the chamber so that further centrifugation of the fog takes place therein to thereby cause the larger droplets to collect on the walls of the conduit and to be refluxed into the liquid.

2. The invention of claim 1 including: a liquid reservoir for storing the liquid from which the fog is produced to be delivered to the chamber; a valve connected between the liquid reservoir and the chamber such that the liquid in the chamber is maintained at a predetermined level.

3. The invention of claim 2 wherein the top of the chamber is removable.

4. The method of forming fog and entraining the said fog into the surrounding atmosphere which comprises: placing liquid from which a fog is to be produced in a chamber; exciting the liquid at an ultrasonic frequency over a broad area such that a geyser is formed within the chamber; introducing gas at higher than ambient pressure into the chamber tangential to the walls thereof at high velocity such that the gas initiates a swirling motion within the chamber and upon contacting the geyser causes the liquid particles therein to swirl in the same direction within the chamber to thereby cause centrifugation such that the larger droplets thereof are refluxed into the liquid; emitting the formed fog into the surrounding atmosphere through a conduit having a smaller radius than the chamber so that further centrifugation of the fog takes place to thereby cause the larger droplets to collect on the walls of the conduit and to be refluxed into the liquid.

5. The method of claim 4 wherein the ultrasonic frequency is of the order of 600 kHz. to 1 MHz.

6. The method of claim 4 including: causing the fog being emitted through the conduit to change direction by an angle of the order of 340° upon entering the conduit to thereby cause the large droplets to be refluxed into the liquid.

7. The method of claim 6 wherein the ultrasonic frequency is of the order of 600 kHz. to 1 MHz.

8. An ultrasonic fog generator for entraining fogs produced from a liquid into the surrounding atmosphere comprising:

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