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SONIC DISTILLATION PROCESS AND APPARATUS

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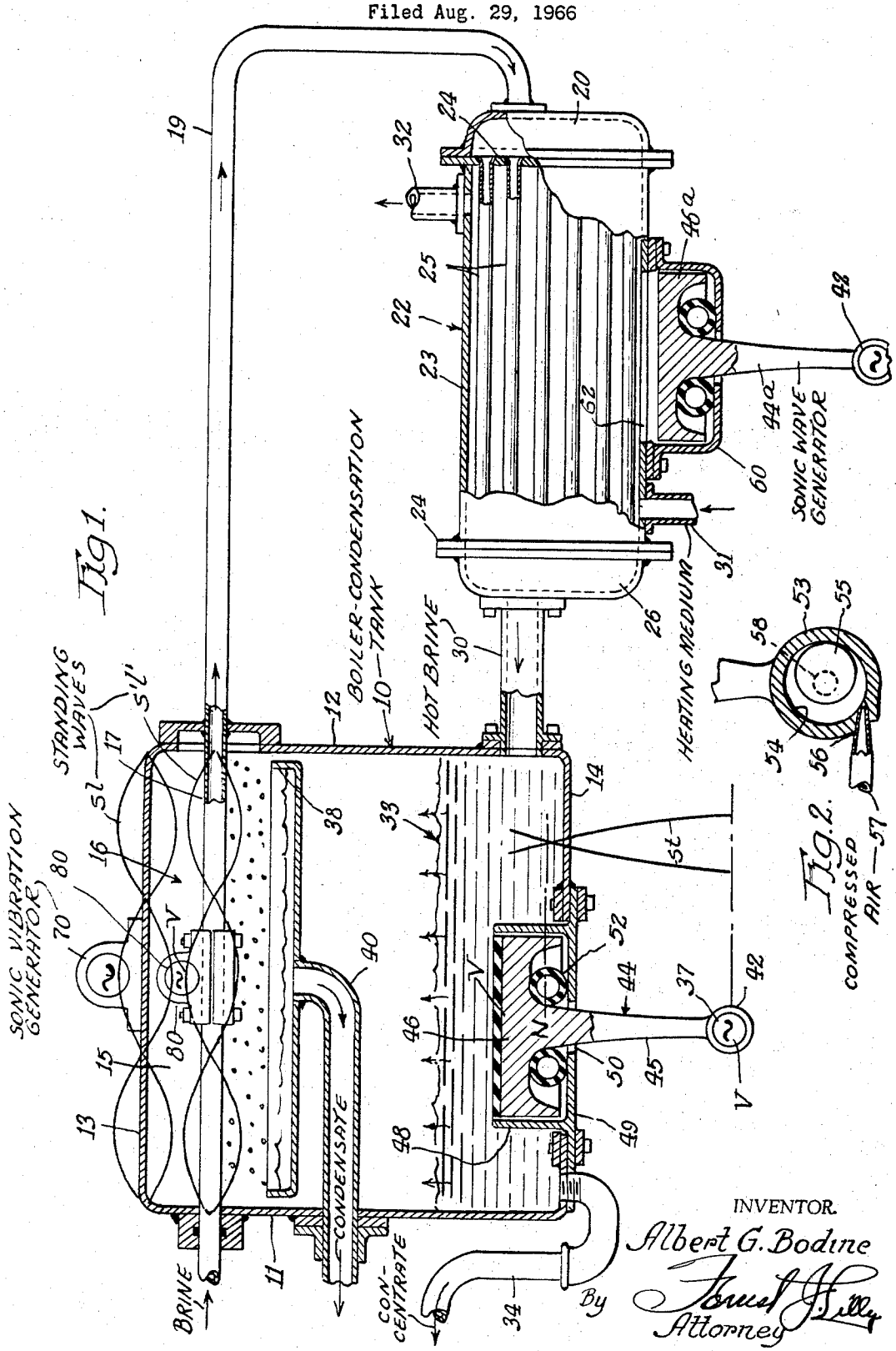


Fig. 1.

Fig. 2.

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SONIC DISTILLATION PROCESS AND APPARATUS

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ABSTRACT OF THE DISCLOSURE

Liquid to be boiled is preheated and simultaneously exposed to sonic vibrations. The liquid is fed from the preheater to a cooler tank. Sonic vibratory energy is generated by means of a sonic oscillator and vibratory resonator which is sonically coupled to the liquid in the boiler tank to create sonic vibrations therein.

This invention relates generally to sonic methods and means for speeding up certain thermodynamic processes involving equilibrium between two phases, such as between the liquid and vapor phases in a distillation process, e.g., as in a desalinization plant.

Such a thermodynamic process consists in effect of the summation of a huge number of minute local transient processes or interactions of differing sizes, activities, or masses and/or consequences occurring simultaneously, and behaves or operates as a whole on a statistical basis in accordance with the average of such relatively minute or elemental local transient processes. In a major aspect, the philosophy underlying the present invention is that, by certain sonic methods and apparatus which I have contrived, the more favorable of the elemental transients participating in the process as a whole can be seized upon, so to speak, and availed of during their transitory existence, to accomplish a favorable statistical shift from the normal average in the process as a whole, so as to improve the net output from the process. Thus minor transient thermodynamic fluctuations of nature favorable to the process are availed of while they persist, and the result is a favorable shift in the statistical average performance of the process.

Speaking generally, consider the condensate output from a distillation process. Clearly, a small percentage increase in vapor evolved at a given temperature, or conversely, vapor condensed at a given temperature, can substantially improve the net output yield of condensate. It is a general object of the invention to accomplish, by special sonic means, such improvement.

The process of boiling is a complicated one whose basic characteristic is an evolution of vapor bubbles within the liquid at a certain boiling temperature, and the rise and escape of these bubbles at the liquid surface. The process involves many variable determinants. Assuming water as the boiling medium, it is most commonly neither pure, nor uniform. The boiling temperature may be considerably above 212° F. because of inclusions or impurities. It also varies with pressure, as is known. Surface tension somewhat elevates boiling temperature above what it would otherwise be. Also, apparently, there are many small localized equilibrium systems within the body of the liquid, comprised of small or minute vapor bubbles wherein vaporization may be momentarily at equilibrium with condensation, and these systems may shift so that vaporization exceeds condensation, leading to rise and release of the vapor, or so that condensation exceeds vaporization, leading to termination of the transient without net result.

Application of a high-energy sonic field to a body of liquid undergoing the boiling phenomenon increases general mobility within the heated liquid by setting up in the

liquid substantial flow oscillations. These are characterized by pressure and velocity fluctuations of considerable magnitude, which have the effect of speeding the vapor bubbles through the liquid body and to and through the liquid surface. The rate of vaporization is thus increased by the improved mobility, both by hurrying along those normally evolved vapor bubbles which would escape from the liquid body in any event, and by speeding to and through the surface the more active vapor molecules, as well as certain small transient vapor bubbles otherwise destined for return to the liquid phase. The average vaporization rate throughout the liquid body is thus favorably shifted.

The sonic field also apparently has the effect of reducing surface tension at the liquid surface, and therefore actually reducing the boiling temperature.

Still further, when the high-energy sonic wave system is super-imposed on the liquid, the pressure excursions of elastic vibration of the fluid body on the negative half-cycles cause cavitation in the liquid, which is of course productive of vapor bubbles. These bubbles, once formed, tend to persist rather than collapsing on the positive half-cycles of the wave, there apparently being a boundary condition at the interface which tends toward retardation of the collapse of the vapor bubbles until the next negative pressure or cavitation half-cycle again occurs. Thus these vapor bubbles tend to persist, and owing to the high mobility of the liquid body under the influence of the sonic wave field, these vapor bubbles caused by cavitation move to the surface and escape, in aid of the boiling process.

The sonic system of the invention also tends to agglomerate minute quantities of air and other gases trapped between liquid molecules, and these gases, thus gathered into larger particles, can then rise and leave as bubbles, further activating the boiling process.

From the above considerations, it will be evident that the boiling process, particularly when subjected to a sonic wave field, is inherently a sporadic process, with changes in conditions from instant to instant. The sonic system, to work really effectively, and to accomplish a large economic benefit, must adapt itself automatically, continuously and speedily to accommodate these changes in operating conditions. It is accordingly a major and most important object of the invention to provide a resonant sonic wave generating system, in combination with a boiling process, which automatically undergoes certain variations in phase angle, power factor and frequency in almost instantaneous accommodation to changes that take place in the boiling process under sonic activation, so that sonic energy application to the liquid to be boiled will be constantly maximized, the vaporization rate will be improved accordingly, and materially improved boiling efficiency thus achieved.

The invention, as indicated above, employs application of a sonic wave field to the liquid to be boiled. This involves the use of a vibratory sonic wave radiator. This radiator and the special later-described resonant sonic driving means behind it operate automatically in a manner to accommodate certain continuously varying conditions in the liquid during boiling. These varying conditions are of two kinds: The first is resistive, or power consuming, and corresponds with resistance in an electrical system, or friction or other energy dissipation in a mechanical system. The second is reactive, or nonpower consuming, corresponding, by analogy to electrical alternating current systems, to the algebraic difference between inductive reactance and capacitance reactance, and by analogy to ordinary mechanical vibration systems, to the algebraic difference between mass reactance and elastic compliance reactance.

These parameters will be somewhat more fully defined

hereinafter. In each case, however, the reactance factors combine algebraically, and the difference of these combines vectorially with the resistance factor or component to form a resultant load impedance.

To return to the process of the invention, the liquid boiling medium represents a large resistive or energy-consuming load factor presented to the sonic wave source, being composed of the resistance of the liquid body to oscillation by the sonic wave and the energy dissipation involved, plus the larger energy dissipation involved in the evolution of vapor bubbles and the resulting general agitation caused by their creation and their movement through the liquid body. Cavitation is apparently also an energy dissipating phenomenon, and there may be other ways in which energy is dissipated. Now, these energy dissipating factors are comparatively irregular, sporadic, and may take place somewhat in bursts. Thus, the resistive "load" in sonically stimulated or activated boiling is a variable one.

Also involved in the sonically activated boiling process are changes in reactance, such as when there are abrupt changes in reactive coupling of the sonic wave radiator to the liquid owing to sudden boiling and release of bubbles. This change in loading reactance changes the reactive environment into which the sonic wave radiator is working. In other words, the characteristic elastic stiffness and inertia of the liquid body presents a reactance which, as seen by the radiator, varies considerably during the boiling process.

The combined resistive and reactive factors thus impose on the sonic wave radiator a load impedance of which all factors are variable, and this variable load impedance functions as a part of a discrete resonant acoustic circuit involved in the system, as will next be described.

The resonant acoustic circuit comprises, first, a sonic wave generator or oscillator of a special orbital-mass type, which, in conjunction with a resonator, which is the component of the circuit, has the desired automatic accommodation to the impedance variations of the load.

My "orbital-mass" vibration generators or oscillators may take various mechanical forms, one of the simplest and best of which involves a roller mass rolling around in a bearing, so that the mass generates a centrifugal force which is reactively opposed by the bearing. The bearing is in a housing, which in response to the centrifugal force so generated, exerts a periodic inertial force on whatever may support it or be coupled thereto. Examples of suitable forms of such orbital-mass generators are disclosed in my Patents Nos. 2,960,314 and 3,217,551.

The resonant acoustic circuit comprises next, as mentioned above, a vibratory resonator, and this member is acoustically coupled to the housing of the orbital-mass oscillator. This resonator terminates in the aforementioned vibratory wave radiator, which is in turn acoustically coupled to the liquid body to be boiled, which comprises, as already mentioned, the variable impedance load. The oscillator is equipped with a driving means or power source, generally in the nature of a motor of some sort, either electrical, pneumatic, internal combustion engine, or any other found suitable. It is important that this driving motor for the oscillator be powered so as to tend to operate at the resonant frequency of the acoustic circuit, and by having the driving motor tend normally to drive the oscillator at a frequency just under that for peak resonance, a number of additional important advantages are gained, particularly when using a driving motor which has a characteristic of inverse speed responsiveness to loading torque imposed upon it by the oscillator and the balance of the acoustic system. These advantages will be spoken of more particularly hereinafter. The driving motor, oscillator, resonator, and the variable impedance load constituted by the boiling body of liquid make up a discrete "acoustic circuit."

Acoustically, speaking, the impedance of the resonantly vibratory resonator, or of any vibratory portion of the acoustic circuit, is a complex quantity proportional to the ratio of force to vibratory velocity at any point along the resonator, or in the acoustic circuit as a whole. As preliminarily mentioned above, the impedance of the load depends upon the vector resultant of the reactances and resistances of the load. This impedance, and the optimum phase angle, power factor and frequency for desired resonant performance, with maximum power delivery to the load, depends upon the magnitudes of these parameters at any particular instant, and can and do vary from instant to instant. The orbital-mass oscillator accommodates automatically and instantaneously in response to these variations in impedance, including change of phase angle of its orbiting mass relative to the motion of the vibrating resonator, with accompanying change of power factor, and/or frequency, assuring thereby effective and sustained delivery of large sonic energy to the load, under which conditions the boiling process is most powerfully sonically activated.

The orbital-mass oscillator adjusts its output frequency to maintain resonance with changes in impedance of the circuit. Thus, in the face of changes in the effective mass and compliance presented by the load, the system automatically adjusts its frequency to itself in optimum resonant operation by virtue of a resonant frequency "lock-in" characteristic of the orbital-mass generator. As mentioned hereinabove, in order to obtain optimal performance, the orbital-mass oscillator and its drive motor are dimensioned and designed so that, with the drive effort properly adjusted, the oscillator will tend to lock in for operation at a frequency just on the low side of that for peak resonance. The oscillator then automatically changes its frequency and also its phase angle and therefore its power factor to correspond with changes in both the resistive and reactive components of load impedance comprised of the boiling body of liquid as the boiling process proceeds and as sporadic variations in activity take place throughout the liquid from instant to instant. At the same time, assuming a drive means powered to establish operation in the range of resonance, and just below the frequency for peak resonance, and assuming also a drive means that has the characteristic of inverse speed responsiveness to load, the drive effort can readily be adjusted so that the system locks in, as already mentioned, at just below the resonant frequency of the circuit, inclusive of the load. An excellent frequency stability is thereby established.

The orbital-mass oscillator as described, coupled to a resonator, particularly an elastically vibratory equivalently half-wavelength standing wave system terminated by a high-impedance wave radiator, with the latter sonically coupled to the liquid body, affords a very powerful vibratory system. Such a system, moreover, can be readily designed with sufficient elastic compliance reactance to counteract the mass reactance of the relatively heavy resonator member and oscillator housing at the resonant operating frequency, and thus virtually cancel out force-wasting mass blocking effects. It is further a definite advantage that the elastic compliance reactance in such a system can readily be made sufficiently large to afford resonant magnification of vibratory amplitudes in the system, and to provide also a large energy storage property (often designated "Q"). The system also has a surprising frequency stabilizing feedback effect from the resonator to the oscillator, provided that the oscillator be designed to deliver a cyclic impulse properly related to the reactance and resistance of the resonator and of the load, so that the oscillator and resonator tend to maintain a frequency just below that for peak resonance, as explained above, and provided further that I drive the oscillator of this combination with a characteristic of inverse speed responsiveness to load. The oscillator then both locks in at such frequency, and automatically adjusts its phase angle to the load resistance. The frequency adjusts to the load reactance. An ideal acoustic system for transmitting large

sonic energy to the boiling body of water is thus afforded.

A further feature of the invention is the use of a sonic wave generating system, preferably again of the orbital-mass oscillator type, for establishing a standing sound wave in the vapor space within the boiler. The sonic standing wave so developed results in agglomeration or gathering together of vapor molecules for effective condensation thereof. The agglomeration effect is owing to migration of vapor molecules to nodal regions of the standing wave established within the vapor space. Minute water droplets also migrate to the nodal regions of the standing wave, and these agglomerate or coalesce to fall out like rain. The advantage of the orbital-mass oscillator and resonator system is that it can accommodate, in a manner analogous to that described hereinabove in regard to the boiling phase of the process, for changes in the total vapor load, and for the condensation rate, by the type of performance hereinabove described by which the orbital-mass system accommodates for both reactive and resistive components of total impedance in the load.

A further preferred and advantageous feature of the particular form of the invention here chosen for illustrative purposes is the use of sonic oscillators, again preferably of the orbital-mass resonance type because of the peculiar advantages thereof hereinabove mentioned, in connection with the condensation tubes of the boiler through which the brine input flows on its way to the heat exchanger. The sonic action so applied to the condensation tubes has a number of effects, one of which is that as vapor is condensed against the outside of the tube, the sonic vibration quickly throws this condensed liquid free so that it can drop into a collection tray. This then instantly exposes the pipe for condensation of further vapor, affording a high performance rate. A much higher performance for a given amount of pipe surface area is thus attained. In addition, the standing wave in the vapor space around the condensation pipes greatly increases the rate of condensation by virtue of migration and agglomeration of the larger vapor molecule groups.

Since both the condensation processes have constantly changing or transient conditions, here again the orbital-mass resonant circuit system, with its ability to accommodate for changes in both resistive and reactive components of impedance, is very beneficial to the economic effectiveness of the over-all system.

It is now important to note that the automatic accommodation characteristic of the sonic system of the invention to changes in resisive reactive impedance of the load results in a favorable shift in the statistical expectation of the system based upon averaging of normal (nonsonic) localized processes. It should be seen that an important contribution made by this invention is the provision of a sonic process to facilitate boiling and condensation which accommodates almost instantaneously to the average of small localized momentary fluctuations in the process and so takes advantage of these to bring about a higher average performance rate.

To summarize certain of the acoustic concepts referred to hereinabove, a sonic resonant system comprising an elastically vibratory resonator member in combination with an orbiting-mass oscillator or vibration generator is employed in my invention. This combination has many unique and desirable features. For example, this orbiting-mass oscillator has the ability to adjust its input power and phase to the resonant system so as to accommodate changes in the work load, including changes in either or both the reactive impedance and the resistive impedance. This is a very desirable feature in that the oscillator "hangs on" to the load even as the load changes.

It is important to note that this unique advantage of the orbiting-mass oscillator accrues from the combination thereof with the acoustic resonant circuit, so as to comprise a complete acoustic system. In other words, the orbiting-mass oscillator is matched up to the resonant part of its system, and the combined system is matched up to the acoustic load, or the job to be accomplished. One manifestation of this proper matching is a characteristic whereby the orbiting-mass oscillator tends to "lock in" to the resonant frequency of the resonant part of the system.

The combined system has a unique performance which is exhibited in the form of a greater effectiveness and particularly greater persistence in a sustained sonic action as the work process proceeds or goes through phases and changes of conditions. The orbiting-mass oscillator, in this matched-up arrangement, is able to hang on to the load and continue to develop power as the sonic energy absorbing environment changes with the variations in sonic energy absorption by the load. The orbiting-mass oscillator automatically changes its phase angle, and therefore its power factor, with these changes in the resistive impedance of the load.

A further important characteristic which tends to make the orbiting-mass oscillator hang on to the load and continue the development of effective power, is that it also accommodates for changes in the reactive impedance of the acoustic environment while the work process continues. For example, if the load tends to add either inductance or capacitance to the sonic system, then the orbiting-mass oscillator will accommodate accordingly. Very often this is accommodated by an automatic shift in frequency of operation of the orbiting-mass oscillator by virtue of an automatic feedback of torque to the energy source which drives the orbiting-mass oscillator. In other words, if the reactive impedance of the load changes this automatically causes a shift in the resonant response of the resonant circuit portion of the complete sonic system. This in turn causes a shift in the frequency of the orbiting-mass oscillator for a given torque load provided by the power source which drives the orbiting-mass oscillator.

All of the above-mentioned characteristics of the orbiting-mass oscillator are provided to a unique degree by this oscillator in combination with the resonant circuit. The kinds of acoustic environment presented to the sonic source by this invention are uniquely accommodated by the combination of the orbiting-mass oscillator and the resonant system. As will be noted, this invention involves the application of sonic power which brings forth some special problems unique to this invention, which problems are primarily a matter of delivering effective sonic energy to the particular work process involved in this invention. The work process, as explained elsewhere herein, presents a special combination of resistive and reactive impedances. These circuit values must be properly met in order that the invention be practiced effectively.

Sometimes it is especially beneficial to couple the sonic oscillator at a low-impedance (high velocity vibration) region, for optimum power input, and then have high impedance (high force vibration) at the work point. The sonic circuit is then functioning additionally as a transformer, or acoustic lever, to optimize the effectiveness of both the oscillator region and the work delivering region.

The invention will be understood more fully by considering a somewhat diagrammatically shown illustrative form of the invention, reference for this purpose being had to the accompanying drawings, in which:

FIG. 1 is a schematic layout of a system in accordance with the invention, parts being shown in elevation and parts in section; and

FIG. 2 is a partly broken away view of a typical simple oscillator of the orbital-mass type.

In FIG. 1 of these drawings, the numeral **10** designates generally a combined boiler and condensation tank, the tank having, as shown, end walls **11** and **12**, a top wall **13**, a bottom wall **14**, a side wall **15**, and another side wall opposite to wall **15**, not shown. The walls of this tank are of steel, and in the illustrative embodiment the upper wall **13** in particular is elastically vibratory in a standing wave pattern, as to be described, while the end walls **11** and **12** are quite stiff so as to fairly firmly support the end edges of the vibratory top wall **13**.

Running longitudinally through the upper portion of tank **10**, and thus through walls **11** and **12** and the vapor space **16** in the tank, are a plurality of water or brine tubes **17**, only one of which is here shown, which serve also as condensation tubes, as will appear. The tube or tubes **17** lead via pipeline **19** to a header **20** at the end of a heat exchanger **22**, the latter having an external casing **23**, conventional tube sheets **24**, heat exchanger tubes **25**, and an outlet header **26**, to which is coupled heated brine outlet pipe **30**. A heating fluid is introduced to the space around the tubes **25** via an inlet **31** and leaves via an outlet **32**. The heated brine pipe **30** opens into the lower end or liquid space of boiler and condenser tank **10**, supplying the heated water or brine to the latter, forming a liquid body **33**. A pipe line **34** withdraws brine from the lower portion of tank **10**, and rises to a level, as shown, to establish the liquid level in the tank **10**.

Below the tubes **17** in the tank **10** is a tray **38** adapted to collect water particles thrown off the tube **17**, and this tray is mounted on and discharges through a pipe **40** leading out of tank **10** as clearly shown.

Mounted in the bottom portion of tank **10** is a sonic circuit means comprised of an orbital-mass vibration generator or oscillator **42**, and an elastically vibratory resonator generally designated by the numeral **44**. The resonator **44** may be embodied in various forms, but in the case here instanced, comprises a downwardly extending and downwardly tapering elastic stem or bar **45**, having at the top an annularly enlarged vibratory head or piston **46**, preferably faced at the top with a layer of rubber-like material such as polyurethane or silicon rubber, in order to increase the coupling coefficient from the piston **46** to the liquid. The piston **46** fits closely within the annular wall **48** of a pan or shroud **49** which is mounted in the lower tank wall **14**, and fastened thereto as indicated. The close spacing presents a high impedance in the liquid annulus between the piston and shroud, so as to minimize loss of energy down past the piston. Stem **45** protrudes downwardly through the bottom wall of the pan **49** by way of an opening **50**, and the resonator **44** is supported by its annularly enlarged head **46** by means of a pneumatic vibration isolator tube **52** of rubber-like material, encircling stem **45** above the bottom of the pan and supportingly engaging the upper extent of the stem **45** and the underside of head **46**, for example as clearly illustrated in FIG. 1. The pneumatic tube **52** is inflated so as to support vibratory action of the resonator, and act also as a seal against the bottom wall of the pan. It engages the stem at a node of the vibratory system, and, being protected from leakage of sonic energy between the piston and shroud, is not subjected to very substantial pressure fluctuations and consequent energy loss from the piston. Moreover, the tube **52** functions as a shunt compliance, or decoupler, to prevent wave generation and high impedance blocking effects on the underside.

The orbital-mass oscillator **42** at the lower terminal of stem **45** may be, for example, any suitable one of a number of those shown in my aforesaid Patents Nos. 2,960,314 and 3,217,551. The oscillator will be referred to in more particular hereinafter, and for the time being it will merely be mentioned that its function is to deliver against the lower end of stem **45** a periodic cyclic force or force component oriented along the direction line of the stem. The stem **45** taken together with the enlarged head **46** is designed to vibrate elastically along the longitudinal direction line of the stem in the classic manner of a half-wavelength elastic bar undergoing resonant elastic vibration in the longitudinal mode, i.e, according to a half-wavelength longitudinal resonant standing wave pattern. Assuming a bar of uniform cross-section, a longitudinal resonant half-wavelength standing wave pattern involves a node, a region of minimized vibration amplitude, at the midpoint, and antinodes, or regions of maximized vibration amplitude, at the two extremities. Each half length of the bar alternately elastically contracts and expands, and the amount of such movement increases progressively from the midpoint to each end of such a bar, as is well known. As is also well known, these vibrations of the two half lengths of the bar take place in opposition to one another, so as to remain in balance with one another. The present device, comprised of the stem **45** and the piston or head **46**, is, very broadly speaking, an equivalent for the classic uniform half-wavelength longitudinally vibratory bar, but a very material improvement thereupon. The structure has, as in the case of the classic half-wavelength bar, a nodal point, here designated at N, and velocity antinodes V at the extremities. In the specific embodiment of FIG. 1, one extremity will be seen to be within the lower end oscillator **42**, and the other at the top of the piston **46**. The structure vibrates along the vertical longitudinal axis with the portion above the node N always traveling in phase opposition to the portion of the structure below the node N. With the specific configuration here given in this illustrative embodiment of resonator, the distance from node N to the lower velocity antinode V may be somewhat greater than a half wavelength, notwithstanding the lumped mass effect of the oscillator because of the tapered and thus considerably slenderized form of the stem **45**. The portion of the structure above the node N, on the other hand, which will be seen to be constituted partly of an upper portion of the stem **45** together with the entirety of the head or piston **46**, is considerably shorter than a half wavelength because of the very great concentration of mass. The upper face or end of the piston **46** then vibrates with high impedance, or in other words, with great force but through small displacement distance and at small velocity amplitude. The lower extremity of the stem **45**, by contrast, vibrates with substantially lower impedance, and therefore with less force amplitude and greater displacement and velocity amplitude. The upper high impedance end of the piston **46** then has the necessary high impedance for effective acoustic coupling to the liquid. As mentioned hereinabove, some improvement in the coupling coefficient is attainable by use of the rubber-like facing on the piston. On the other hand, a lower impedance condition has been provided at the lower end of the stem, permitting use of an orbital-mass oscillator **42** having an output impedance somewhat less than would otherwise be required. Assuming an oscillator **42** driven at the resonant frequency for the resonator **44**, a longitudinal resonant standing wave will then be set up in the structure as diagrammed at *st* in FIG. 1, wherein the horizontal distance between the two lines of the diagram represents the vibration amplitude of the resonator **44** at corresponding points along the latter. It should of course be understood that, as described in full particular in the introductory portion of the specification, very great advantage is derived from so designing and driving the oscillator that it tends to operate at a frequency just under the peak of resonance.

It should be mentioned that the configuration of the downwardly tapering stem **45** joining the enlarged piston **46** at the top to the oscillator at the bottom is in effect an acoustic lever or transformer, matching a lower impendance oscillator **42** at the lower end to a relatively high impedance radiator **46** at the top. The system is thus an acoustic transformer, giving optimized impedance for the separate special functions at the terminations. Also, attention may be called to the fact that the relatively short distance from the node N to the upper antinode V is owing to the large concentration of mass within the head **46** or piston, and that by the same token, the oscillator **42** at the lower end represents some concentration of mass such as will raise the lower velocity antinode V somewhat. The large "lumped" masses tend towards shortening of the distances from the node to the upper and lower antinodes, whereas the downward tapering or slenderizing of the bar **45** increases the elastic compliance in this part of the device, and progressively reduces the impendance downwardly along the stem. The mass and elasticity reactances

of the vibratory resonator are thus, by a balance of these parameters, brought towards equalization with one another at the resonant frequency, with the very desirable consequence of reduction or elimination of oscillator force otherwise consumed in the vibration of the masses.

In FIG. 2 I have shown a partially broken away view of a simple and illustrative orbital-mass type oscillator **42**. It comprises simply a housing **53** on the lower end of stem **45**, with a cylindrical bearing surface **54** therein for a cylindrical orbital-mass rotor **55**, the diameter of the rotor **55** being somewhat less than that of the race **54**, for example as illustrated in FIG. 2, and the rotor **55** being adapted to travel in an orbital path guided by the bearing surface **54**. The rotor **55** is driven in this orbital path by air under pressure introduced tangentially into the chamber defined by bearing surface **54** via a tapering nozzle **56** fed with air under pressure through a hose or pipe **57**, the latter leading from a suitable source of air under pressure. Spent air escapes from the oscillator housing via a port such as **58**. There is normally included some controllable means, not shown, for regulating the flow of pressure air to the oscillator. The pressurized air introduced into the oscillator is thus controlled to cause the rotor **55** to gyrate or follow its orbital path around the raceway **54** at a frequency corresponding to the resonant frequency of the liquid-loaded resonator **44**, or just below the peak of such resonance, as explained hereinabove. The driving means for the oscillator thus in this case comprises a fluid pressure system, affording considerable "slip" between the introduced air and the rotor **52**, so that the oscillator has the desirable characteristic of slip in the air stream, producing a substantial inverse speed responsiveness to the load portion of the acoustic circuit.

The heat exchanger **22** of the system is preferably equipped with a sonic wave generation system and resonator of the nature just described, utilizing a resonator **44***a* exactly like resonator **44**, an oscillator **42***a* exactly like oscillator **42**, with the piston portion **46***a* of the oscillator **42***a* this time accommodated in a pan **60** hung from the bottom wall of the heat exchanger tank with a large port **62** affording unobstructed communication between the interior of the pan and the heat exchanger tank. The piston **46***a* radiates sound waves upwardly into heating liquid of the heat exchanger, with the effect of scrubbing away heat-insulated boundary layers on the surfaces of the heat exchanger tubes **25**, and thus improving heat transfer.

The system as so far described then operates as follows: Brine is circulated inwardly through the brine tubes **17** running through the vapor space of the boiler and condenser tank **10**. This brine then flows via line **19** to the heat exchanger, through the tubes **25** thereof, which are surrounded by a heating fluid circulated between an inlet **31** and an outlet **32**. The brine is thereby heated to a temperature typically of the order of 250° F., and thence introduced, via pipe **30**, into the lower end of the tank **10**. Oscillator **42** is then driven, and the orbitally traveling cylindrical rotor **55** then exerts on the oscillator housing **53** a force vector which rotates about the central axis of the bearing **54** at some frequency determined by the pressure and flow of air into the chamber of the oscillator. Only the vertical component of the rotating force vector so developed is useful, and this component is augmented and amplified by vertical vibration amplification of the resonant stem **45** as the rotor **55** of the oscillator **42** comes up to resonant frequency with increasing air flow to the oscillator. The system can be readily controlled to produce the desired resonant frequency operation, the manifestations of resonance being unmistakably evident, and it being a very simple matter to control the air flow to establish the operating frequency as desired, below the peak of resonance.

With the above conditions established, the piston member **46** radiates strong sonic vibrations into the liquid body **33**. These sonic vibrations can be radiated into the liquid body **33** at large, or, with increased advantage, so as to establish standing wave patterns in the liquid. In the first case, compressional waves are transmitted through the liquid body causing pressure and oscillations therein such as are characteristic of any sound wave transmission. It is also possible to set up a standing wave system, with nodes and antinodes. For example, the sound waves radiated from the top of the radiator piston **46**, upon encountering the interface between the liquid body **33** and the vapor space above, are reflected back downwardly; and if the height of the liquid over the piston corresponds properly with the vibration frequency of the piston, certain known interference phenomena take place with the result that a standing wave system is established within the body of the liquid. Such a system will of course have regions of maximized and minimized liquid oscillation velocities and pressure variations, leading to materially increased mobility within the liquid body, and ease and speed of travel of the evolved vapor bubbles through the body of the liquid.

It was explained in complete detail within the introductory portion of the specification how such sonic activation increases and facilitates the process of boiling. No claim of course is made that water is boiled with a lower heat of vaporization. The process of the invention, instead, facilitates and speeds up the boiling process, affording increased throughput per hour, for example, within a plant of a given scale. As mentioned hereinabove, the invention produces a condition within the boiling body of water by which the vapor of small and often transient boiling-condensation equilibrium systems can be removed therefrom, and by which vapor molecules, as well as all vapor bubbles evolved in the boiling process, are additionally mobilized and thus rise from the body of liquid in reduced time, or with greater speed. A favorable shift is thereby obtained whereby the evolved vapor is released, not with lesser heat of vaporization, but at an accelerated rate. Also, with a high-amplitude sonic wave, cavitation is produced on the negative high cycles, and the increased mobilization of the resulting vapor bubbles permits these bubbles to be released before they again collapse. It was explained above how these bubbles tend to persist longer than a negative half-cycle of the wave, and under the sonic mobilization condition of the invention, they are sustained long enough to escape, and thus coact with the normal boiling process to improve the rate of vaporization of the liquid. The system also reduces surface tension, and thus permits boiling and release of vapor from the surface of the liquid at a lower temperature.

A further important feature of the invention is to create a sonic wave condition, preferably a sonic standing wave, within the tank **10** in the condensation region thereof.

In accordance with the preferred practice of the invention, I mount on the top wall **13** of tank **10**, typically and in this case midway of the length dimension of the tank, a sonic vibration generator or oscillator, again of the orbital-mass type. Such a vibration generator is designated at **70** in the drawings, and it will be understood that the generator **70** may be of the type of FIG. 2, for example, containing an orbitally traveling mass roller, or may be any of the orbital-mass types referred to hereinabove. The oscillator **70** is driven at a frequency to create a lateral standing wave in the top wall **13** of the tank, which possesses sufficient elasticity to develop such wave action. In the present case, the end walls of the tank are stiff enough to remain fairly stationary during the lateral vibratory action of the wall **13**, so that with a proper frequency, a one and one-half wavelength standing wave is developed, with a pattern such as designated at *sl*, having nodes or pseudonodes N at the end walls of the tank and at half-wavelength distances inwardly therefrom, and three intervening velocity antinodes V. It will be understood that the top tank wall **13** elastically deflects as represented by the standing wave diagram *sl*, producing corresponding pressure and velocity conditions in the

vapor space. The bottom surface of the wall **13** thus radiates sound waves downwardly into the region of the tank where condensation is to occur. This wave action results in an action characterized by condensation of the vapor into minute droplets which immediately agglomerate and fall out of the vapor space like rain. Such agglomeration effect is owing to migration of vapor or water molecules, or fine water droplets, to nodal regions of the standing wave within the vapor space. By the principle of "least work," such minute particles or droplets within the standing wave area migrate from the regions of maximum vibration displacement and velocity amplitude to regions of minimized displacement and velocity amplitude, so that minimized work is done thereon.

It will be recognized that the oscillator **70** together with the elastically vibratory tank top **13** vibrating in a resonant standing wave pattern will be seen to be an orbital-mass oscillator and resonator system, with a variable load, the latter varying with changes in the total vapor load and in the condensation rate. The advantage here is that this system can accommodate or self-regulate itself in response to changes in the total vapor load and for the condensation rate, in accordance with principles discussed hereinabove, responding, in this connection, to both changes in reactive and resistive impedance such as is useful in gaining an optimum performance rate.

A further advantageous feature of invention is the use of orbital-mass type oscillators mounted on the condenser tubes **17**. Such an oscillator **80** is shown mounted on one of the tubes **17** in the drawings, and is shown as placed on the tube **17** midway between the end walls **11** and **12** of the tank, i.e., at a selected velocity antinode V. The end walls of the tank again establish nodal regions, and the oscillator **80** is again driven so as to provide a resonant standing wave in the tube **17**, such as diagrammed at *s'l'*. The oscillator **80** is again driven, through any suitable source of drive, so as to generate the resonant standing wave pattern *s'l'* in the tube **17** corresponding to that set up in the top wall **13**. The wave pattern is again assumed to be a lateral type, though gyratory or other modes may be used. It will of course be understood that the vapor condenses on these tubes **17** and tends to collect thereon. The wave action developed in the tubes **17** quickly throws off this condensed water so that it can drop into the collection tray **38**. This exposes the tube for condensation of further vapor, and so improves the performance rate. The result is higher performance for a given amount of pipe surface area. Condensation onto the pipes **17** is also promoted by the standing waves in the vapor space which materially increase the rate of condensation by virtue of migration and agglomeration of the larger vapor molecule groups or combinations to the nodal regions of the wave where they are crowded together.

Referring again to the orbital-mass oscillators **80**, these may in many instances be either electric-motor driven, or shaft driven, many illustrative forms of which are shown in my aforementioned patents. These types of oscillator drive avoid any problem which might arise out of discharge of air into the tank. Air driven oscillators may, however, be successfully used provided the air discharged into the vapor space does not result in a shift in the heat balance.

It is noted that the system of the invention in its preferred, illustrative form employs, in different parts of the apparatus and for different purposes, use of sonic waves generated in liquid, solid and in vapor media.

Since both of the sonic systems involved in the condensation and collection process have transient or constantly changing conditions, here again the orbital-mass oscillator and resonator combination, with its ability to accommodate for or adjust to changes in both resistive and reactive impedance, is very beneficial to the economic performance of the over-all system. Not only is the boiling process benefited by the favorable shift in statistical average performance by the described accommodation or response characteristic of the sonic system, but also the condensation system is similarly benefited. The economic performance of a given condensation and evaporation plant, with the addition of the sonic wave improvements of the present invention, is thus significantly improved.

It will be understood that the particular embodiment of the invention here chosen for illustrative purposes is merely for illustration and not to be taken as limitative on the invention, particularly in its broader aspects, since numerous changes in design, structure, and arrangement may be made in the equipment without departing from the spirit and scope of the appended claims.

I claim:

1. The process of facilitating a boiling process, that comprises:

providing a body of liquid to be boiled in a boiler tank;

heating said liquid in a preheater preceding the boiler tank and exposing the liquid to sonic vibrations;

generating vibrations by driving an orbital-mass rotor repeatedly in an orbital path around the surface of a bearing;

coupling said bearing to a resonator, whereby to transmit said vibrations to said resonator, and adjusting said vibrations to the resonant frequency range of said resonator; and

acoustically coupling said oscillator and resonator to said liquid in said boiler tank, so as to create sonic vibrations in said liquid.

2. The subject matter of claim **1**, including also:

driving said orbital-mass rotor with a drive effort that is inversely responsive to torque load on said bearing, and at a frequency which is in the range of resonance but on the low side of that for peak resonance amplitude.

3. The subject matter of claim **1**, including causing cavitation in the liquid body by said sonic vibrations by establishing a sonic pressure wave therein, at an amplitude sufficient to cause the negative pressure half-cycles of the wave to drop to the vaporization pressure of the liquid.

4. A sonically aided boiler comprising:

a boiler tank for holding a body of heated liquid to be boiled;

an orbital-mass oscillator;

a heater for preheating the liquid prior to discharge into the boiler tank; and

a vibratory resonator coupled to said oscillators and vibrated in its resonant frequency range thereby,

said oscillator and resonator including a vibratory sonic wave radiator immersed in and thereby coupled to said body of liquid.

5. The subject matter of claim **4**, including means for driving said oscillator including a power source having the characteristic of inverse speed responsiveness to torque load, and which is powered to drive said resonator in the range of resonance but on the low side of the frequency for the peak of resonance for said resonator.

6. The subject matter of claim **4**, wherein said oscillator comprises an orbital-mass rotor, and a housing having a bearing engaged by and defining an orbital path for said orbital-mass rotor; and

said oscillator comprises an equivalent half-wavelength longitudinally elastically vibratory member of generally elongated form having velocity antinodes at its extremities and an intervening node, and having said wave radiator at one extremity thereof positioned within and thereby acoutically coupled to said body of liquid, and having said housing of said oscillator fixed on the other extremity thereof.

7. The subject matter of claim **6**, wherein said elastically vibratory member includes a stem, a radially enlarged piston on one extremity of said stem to form said wave radiator, and said housing of said oscillator at the other end thereof.

8. The subject matter of claim **4**, including also an

elastically vibratory resonator in proximity to the vapor space in said tank above the liquid body therein;

an orbital-mass oscillator coupled to said resonator and including a vibratory radiator exposed to vapor and any water droplets in said space and operable to set up in the vapor in said space a resonant sonic standing wave; and

means located in said tank for collecting liquid condensed from vapor in said vapor space.

9. The subject matter of claim **4**, including also a cooled, elastically vibratory, resonating condenser in the vapor space in said tank above the liquid body therein;

an orbital-mass oscillator coupled to said resonating condenser and operable to set up resonant standing wave vibration thereof; and

means located in said tank below said condenser for collecting liquid thrown off and dropping from said condenser as a result of said standing wave vibration.

10. The subject matter of claim **9**, wherein said condenser comprises a cool water tube extending within said vapor space.

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