March 19, 1963 E. E. LINDSEY 3,081,979

SONIC MIXING APPARATUS AND METHOD

Filed Nov. 20, 1959 2 Sheets-Sheet 1

FIG. 1.

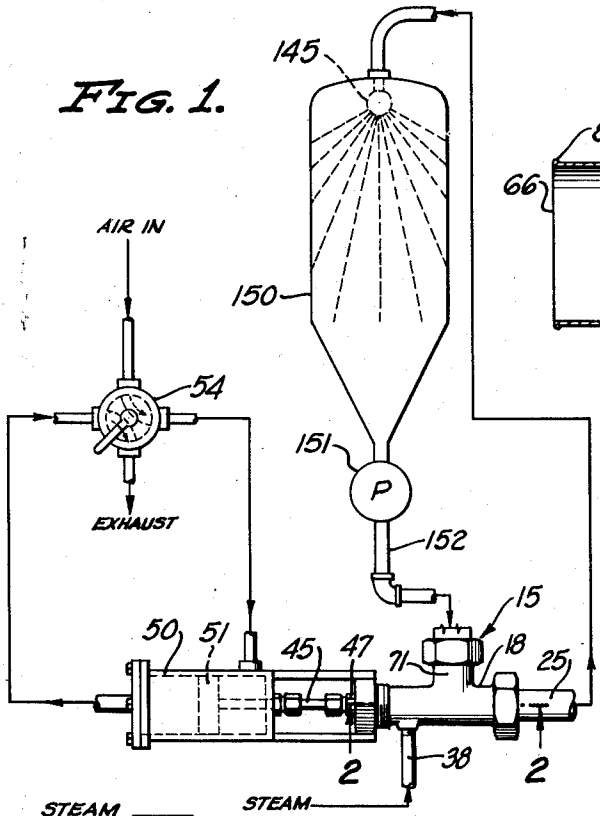


FIG. 4.

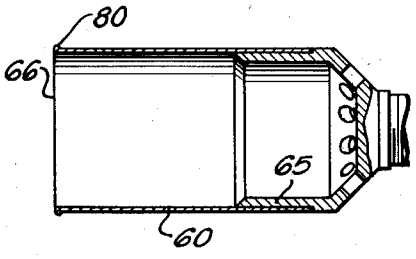


FIG. 5.

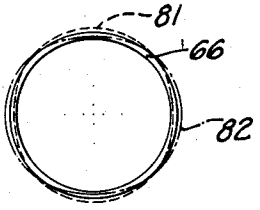


FIG. 2.

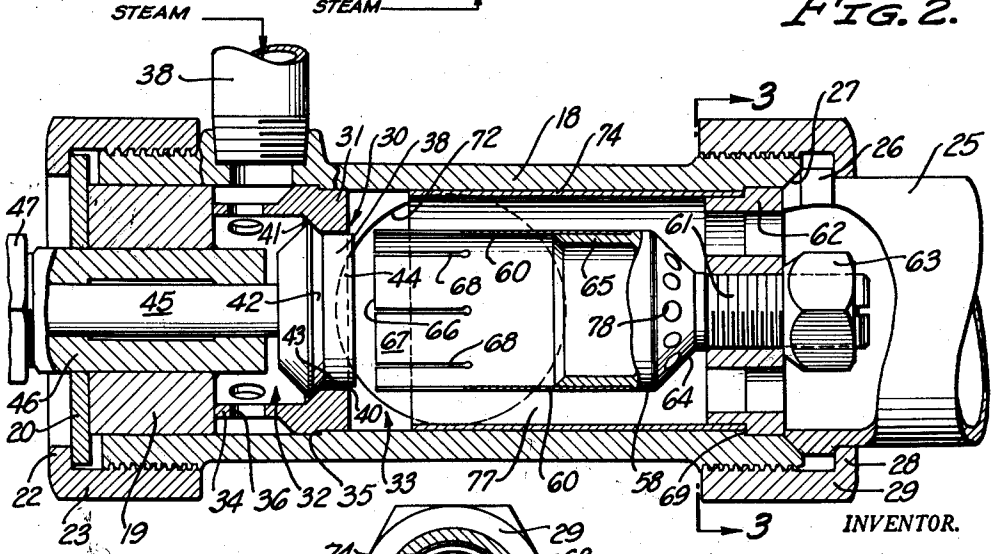
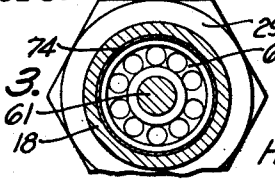


FIG. 3.



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SONIC MIXING APPARATUS AND METHOD

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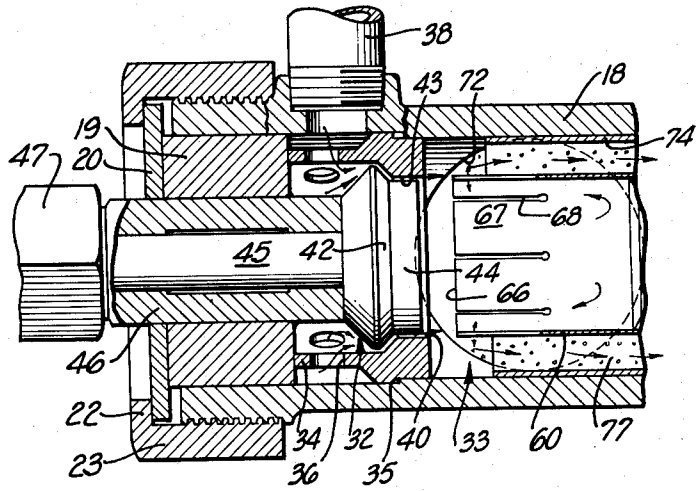


FIG. 6.

FIG. 7.

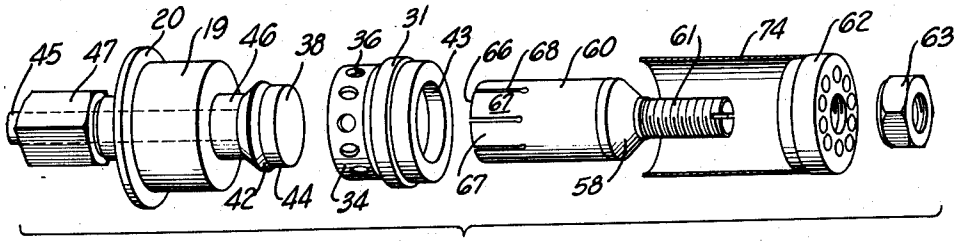
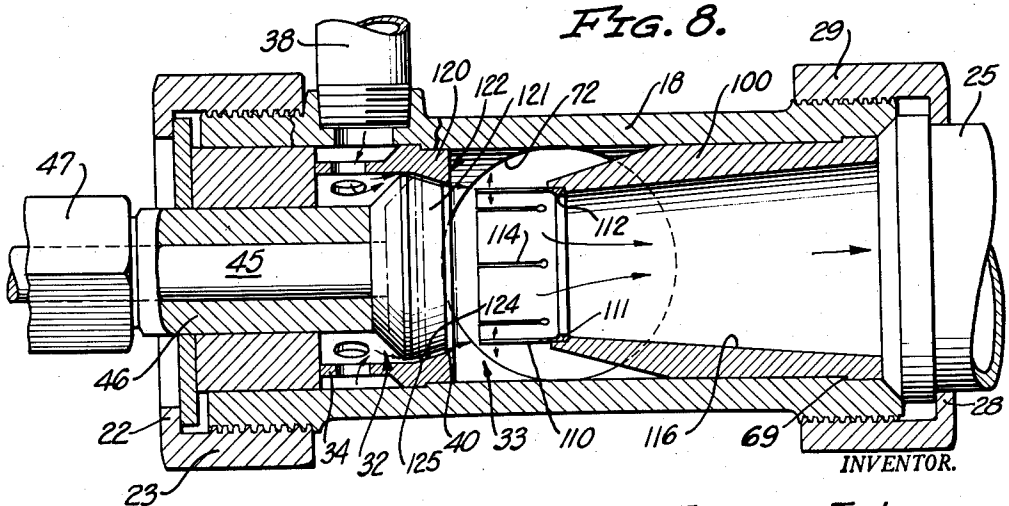


FIG. 8.



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United States Patent Office 3,081,979 Patented Mar. 19, 1963

3,081,979

SONIC MIXING APPARATUS AND METHOD

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Filed Nov. 20, 1959, Ser. No. 854,381
9 Claims. (Cl. 259—1)

My invention relates to mixing devices and methods and more particularly to the intense mixing or homogenization of dissimilar fluid materials. It will be exemplified as applied to the making of toppings or cream substitutes from vegetable oils although its uses are in nowise limited thereto, the invention being capable of forming permanent emulsions or suspensions of a wide variety of materials.

It has been found that strong cavitation effects leading to intense mixing can be induced by jetting a gaseous medium against the free end of a vibratory member to set same into rapid vibration, usually in the ultrasonic range, a stream of the material to be mixed being brought into the vicinity of the vibrating member. It is an object of the invention thus to mix such a stream of material. Within the concepts of the invention such a stream should be a liquid stream but it can be composed of one or more liquids with or without other gaseous or solid particles dispersed therein. The terms "liquid stream" or "stream of liquid material" are used to include such single or multiple-phase systems.

In the preferred practice of the invention the gaseous medium used to set up the vibrations is one of the desired components of the ultimate mixture and is mixed with the material of the liquid stream as a result of the vibrations it creates. It is an object of the invention thus to employ the vibration-inducing gaseous medium as one component of the ultimate mixture.

It is not essential that the gaseous medium remain in its same physical or chemical state in the ultimate mixture. For example, it may be selected to react chemically with some component of the liquid stream. More commonly there may be some change in its physical state. A particularly advantageous operation is to employ steam as the gaseous medium for inducing the vibrations and at the same time heating the material being mixed. If the liquid stream is of lower temperature the steam will condense in situ in the material of the stream, forming minute droplets of water which may be very advantageous in the ultimate product. It is an object of the invention to induce vibrations in a vibratory member by directing a steam jet thereagainst while delivering a liquid stream to the zone of vibration, the steam and the liquid mixing in such zone, the steam condensing in situ to form minute dispersed droplets of water in the liquid and raising the temperature of the material being treated to such temperature as may be desired and advantageous.

My earlier Patent No. 2,277,120 discloses prior equipment that has been widely used in the mixing or homogenization of various materials. The materials are recirculated in a closed path through a chamber by use of a high-pressure pump and a multi-orificed discharge head, the process being batch or semi-continuous. The present invention can be employed in conjunction with such prior equipment and can effect an intense mixing or homogenizing action on the recirculated materials to such extent that the mixing time can sometimes be decreased almost ten fold. In other instances the invention can be used by itself to exert an intense mixing action on a liquid stream. In either instance the invention effects many economies in equipment, space and time. It is an object of the invention to induce such economies.

It is a further object of the invention to provide a quick-acting position-controlling means for controlling the relative positions of two nozzle members and thus controlling the flow of the gaseous medium therebetween.

Further objects reside in the combination of the aforesaid mixing device and auxiliary equipment by which the material to be mixed can be recirculated continuously through the vibratory zone. In this way it is possible, for example, to build up the content of condensate to a desired value while still obtaining a more thoroughly mixed product.

Various other objects and advantages will be evident to those skilled in the art from the following description of exemplary embodiments.

Referring to the drawings:

FIG. 1 is a pipe-line diagram showing the invention incorporated in an apparatus similar to that shown in my earlier Patent No. 2,277,120;

FIG. 2 is a sectional view taken along the line 2—2 of FIG. 1;

FIG. 3 is a sectional view taken along the line 3—3 of FIG. 2;

FIG. 4 is a fragmentary sectional view, similar to FIG. 2, showing an alternative vibratory member;

FIG. 5 is a view of the forward edge of the vibratory member taken as indicated by the arrow 5 of FIG. 4 and indicates diagrammatically one type of vibration that is possible with this type of vibratory member;

FIG. 6 is a view similar to FIG. 2 illustrating the elements in operative position;

FIG. 7 is an exploded view of the elements of FIG. 2 with slight modification; and

FIG. 8 is a sectional view of an alternative embodiment of the invention.

Referring particularly to FIGS. 1–3, the mixing apparatus is indicated generally by the numeral **15** and is shown as including a tubular housing **18** threaded at opposite ends. The left-hand or entrance end of the tubular housing is closed by a massive ring **19** held in place by a washer **20** which is engaged by a flange **22** of a collar **23** threaded to the housing. The right-hand end of the housing **18** as viewed in FIG. 2 communicates with an exit conduit **25** carrying a beveled flange **26** which is forced against a correspondingly beveled seat **27** of the housing by a flange **28** of a collar **29**.

A nozzle **30** is disposed within the housing **18** and includes an outer annular member **31** dividing the interior of the housing **18** into an inlet chamber **32** and a mixing chamber **33**. The outer annular member **31** provides a neck **34** extending rearwardly to be engaged by the forward face of the massive ring **19**. By tightening the collar **23** a shoulder of the annular member **31** is pressed against a shoulder **35** formed by a counterbore of the housing **18**, forming a fluid tight fit.

Steam or other gaseous medium is supplied by a pipe **38** to the inlet chamber **32** through a plurality of holes **36** drilled radially in the neck **34**. The zone outside the neck **34** acts as a manifold to distribute the steam or gaseous medium uniformly around the periphery of the inlet chamber **32**.

The nozzle **30** includes also an inner annular member **38** cooperating with the outer annular member **31** in defining a narrow annular orifice **40** interconnecting the inlet chamber **32** and the mixing chamber **33** and discharging a high-velocity annular stream into the mixing chamber in a forward direction substantially parallel to the axis of the housing **18**. One of the annular members **31, 38** is made movable relative to the other to control the discharge of the gaseous medium through the narrow annular orifice **40**. As shown, the outer annular member includes a rearwardly facing conical surface **41** mating with a forwardly facing conical surface **42** of the inner annular member **38**. These annular members re-

spectively have substantially cylindrical surfaces 43 and 44 extending forwardly from the respective conical surfaces and providing therebetween the narrow annular orifice 40 of this embodiment.

A suitable position-controlling means is employed to determine and fix the relative positions of the annular members 31 and 38 of the nozzle. In FIGS. 1 and 2 this means includes a rod 45 secured to the inner annular member 38 and journalled by a sleeve 46 for longitudinal movement in the direction of the axis of the housing 18. A suitable gland 47 seals the rod 45 in its to-and-fro movement. Such movement is controlled by an actuator shown as including a cylinder 50 in which slides a piston 51 connected to the rod 45. The position of the piston is determined by air or other fluid supplied to and exhausted from opposite sides of the piston by use of a conventional four-way valve 54. When in the position shown, air is delivered to one side of the piston and exhausted from the other to permit rearward movement. When in another position the supply and exhaust of air will be reversed so that the piston will advance forwardly. In a third position the volumes of air or other fluid on opposite sides of the piston will be entrapped to lock it in position. In this way it is possible quickly to open, close and adjust the nozzle 30 from a remote point and thus control accurately the gaseous medium issuing from the narrow annular orifice 40.

The high velocity annular jet of steam or other gaseous medium issuing from the narrow annular orifice 40 into the mixing chamber 33 is employed to activate a vibratory means therein. This vibratory means comprises generally a base member 58 at a position downstream from the orifice 40 and a tubular vibratory member 60 affixed thereto. In the embodiment of FIGS. 2, 6 and 7 the base member 58 is supported by a threaded shank 61 extending through the central opening of a spider 62 and clamped rigidly thereto by a locknut 63. The base member includes a diverging portion 64 terminating in a relatively massive sleeve 65. This sleeve is machined to receive and provide a shoulder abutting one end of the tubular vibratory member 60.

In this embodiment of the invention the tubular vibratory member 60 is shown as a relatively thin-walled steel tube with its rear portion fitting over and positioned by the sleeve 65 of the base member 58 and its forward portion terminating in a forward edge 66 positioned in the path of the high-velocity jet of gaseous medium from the narrow annular orifice 40. The arrangement is such that this high-velocity jet will rapidly vibrate the forward end of the member 60, usually at frequencies in the ultrasonic range. In the embodiment under consideration, the forward portion of the member 60 provides several reed-like cylindrical segments 67 because of a plurality of slots 68 spaced around the periphery of the member 60 and extending from the forward edge 66 in a direction substantially parallel to the axis of the housing 18. The free period of vibration of each reed-like cylindrical segment 67 depends upon a number of factors including the thickness and character of the material, the length of the segment (determined by the depth of the slots 68) and the width of the segment (determined by the spacing of the slots 68). It is within the contemplation of the invention to employ slots 68 of equal length and equal spacing as shown. On the other hand it is sometimes advantageous to make some of the slots longer than others and/or to space them so that the cylindrical segments 67 are of unequal width, thereby making it possible to have a group of segments vibrating at substantially the same frequency or widely divergent frequencies.

The vibratory member 60 is preferably mounted in such a way that the distance between its forward edge 66 and the nozzle 30 is adjustable. In this respect the threaded shank 61 permits such adjustment as compared with the spider 62 which is locked in place by being pressed against a shoulder 69 of the housing 18 by tightening of the collar 29.

A liquid stream to be mixed is advanced past the forward portion of the vibratory member 60 as the latter is vibrated by the gaseous medium issuing from the nozzle 30. This liquid stream may enter the mixing chamber 33 at various positions. As shown in FIGS. 1 and 2, the liquid stream enters sidewardly through a leg 71 of the housing 18 which provides a circular inlet passage 72. It is preferable that this inlet passage open on the mixing chamber 33 at a position near the forward edge 66 of the vibratory member. To control the effective area of this inlet passage 72 and its position relative to the forward edge 66 I have successfully used a sleeve 74 carried by the spider 62 and extending immediately inside the housing 18 to cover a portion of the circular inlet passage 72, leaving a segment thereof open as suggested in FIG. 2.

The liquid stream thus introduced spreads around the mixing chamber 33 and is acted upon or disrupted by the intense cavitation effects of the vibration. The liquid stream can leave the mixing passage exclusively through an annular space 77 within the housing 18 around the vibratory member, passing into the exit conduit 25 through the openings of the spider 62. This condition is suggested in FIGS. 6 and 7 where the interior of the vibratory member is completely closed by its supporting base member 58. With such an arrangement the liquid inside the vibratory member can be replaced only by flow through the slots 68 or by flow through the zone between the forward edge 66 and the nozzle 30. This mode of operation has been used successfully. In other instances, however, it is desirable that some or all of the mixed product leave the mixing chamber 33 from a zone inside the tubular vibratory member 60. In FIG. 2 holes 73 in the diverging portion 64 of the base member 58 permit some of the mixed product to flow therethrough to the exit conduit 25 from the interior of the tubular vibratory member 60 while other portions of the mixed product flow along the annular space 77. In the embodiment of FIG. 8, to be described, all of the mixed product leaves from the interior of the vibratory member.

In certain instances it is possible to induce rapid vibration of segments of the forward end of a tubular vibratory member even if these segments are joined together. For example, it is sometimes possible to eliminate the slots 68 in the vibratory member 60 as suggested in FIGS. 4 and 5. The forward edge 66 is here continuous and may be equipped with a small peripheral bead 80 to increase cavitation and thus the mixing effects due to the pressure changes resulting from cavitational effects. This bead is not always essential but it is desirable that the forward edge 66 be in the path of the jet of gaseous medium discharged from the nozzle. The pattern of vibrations set up in the free end of such a tubular vibratory member is not yet completely understood but may be similar to the vibrations of a bell when struck by a hammer. The vibratory pattern undoubtedly involves transient deviations from circularity to oval form in different planes at different times. This type of vibration is suggested in FIG. 5 where the dotted line 81 suggests a momentary deviation to oval form in a vertical plane at one instant while the dot-dash line 82 suggests a momentary deviation from circularity in a horizontal plane at another instant. Such deviations are of course not limited to vertical and horizontal planes but can take place in intermediate planes. By proper design vibration frequencies in the sonic or ultrasonic range can be achieved but the latter appear to be more effective in creating the cavitational mixing desired.

Whether the forward segments of the vibratory member are separate as in FIGS. 2, 6 and 7 or joined together as in FIGS. 4 and 5, the intense mixing action is believed to take place by cavitation effects at two locations. When any segment is moving inwardly there will be an

intense cavitational effect at the outer surface of the segment. At a succeeding time when the segment is moving outwardly there will be intense cavitational effects immediately inside the segment. Both cavitational actions are intense and are believed to be important in creating the desired mixing and disruption of the molecular structure of the product being treated.

The condensation of the steam in situ is also effective in creating an intense mixing action aiding that produced by cavitation. The condensation of each steam particle is extremely rapid, causing a percussive collapse inducing forces similar to those experienced in water hammer phenomena as the surrounding liquid contracts against a liquid condensate particle that has resulted from the volumetric collapse of a steam particle. A steam jet inducing the vibrations and desired mixing of the invention will provide billions of dispersed steam particles which experience volumetric changes of the order of 1700:1 when condensing.

In instances where the mixed product is to be withdrawn exclusively from the interior of the vibratory member, the construction of FIG. 8 can be utilized. Here a base member **100** fits the interior of the housing **18** to eliminate the annular space **77** and the use of the sleeve **74** previously described. The base member **100** provides a flange which seats against the shoulder **69** previously described, being thus held in place by the collar **29**. A tubular vibratory member **110** provides a reinforcing bead **111** and is mounted in a counterbore **112** of the base member **100**. In this embodiment the tubular vibratory member **110** is relatively short, the slots **114** thereof extending almost to the point of support. Likewise the circular inlet passage **72** here remains open. The mixed product advances through a tapered passage **116** to the exit conduit **25**.

Another constructional difference suggested in FIG. 8 is in the shape of the outer and inner annular members **120** and **121** forming the nozzle **122**. In this embodiment the conical and substantially cylindrical surfaces **42** and **44** of the inner member and **41** and **43** of the outer member are merged, the narrow annular orifice **40** being formed between a conical surface **124** of the outer member **120** and a conical surface **125** of the inner member **121**. The resulting high-velocity jet is still directed forwardly along the mixing chamber **33** albeit in a direction which slightly converges. This is often advantageous inasmuch as the fluid medium then traverses the forward edges of the segments of the vibratory member in a direction slightly angled relative to the longitudinal dimension of such segments and produces shear effects. In addition, the width of the annular orifice **40** can be very accurately controlled by the actuator previously described with reference to FIG. 1.

If the gaseous medium is a permanent gas such as air, nitrogen, carbon dioxide, etc. its presence in the mixed product can serve to aerate the latter. This action is often desirable as in the production of emulsions of high fat content. For example the invention can be used to emulsify vegetable oils or liquid animal fats with nitrogen alone or combined with CO_2, CO or other gases. If however the gaseous medium is saturated or superheated steam and if the liquid stream is at a lower temperature, the steam not only induces the vibration but condenses in situ in the liquid to heat same and form extremely small droplets of water which remain as a part of the mixed product as it is withdrawn, being stabilized either by their extremely small size or by the presence of emulsifying agents. This type of action is particularly desirable in the production of whipped toppings, etc. For example the invention can be employed to produce a whipped cream substitute by using steam at temperatures of about 300–380° F. in apparatus similar to FIG. 8 to emulsify a mixture of vegetable protein, vegetable and/or nut oils and an emulsifying agent such as soy lecithin, plus flavoring and/or sweetening materials.

The mixing apparatus thus far described in detail can be used to continuously mix the ingredients of a liquid stream. In some instances, however, it is desirable to employ the invention in a recirculation system whereby a batch of the material can be processed by repeated passage through the mixing chamber. In FIG. 1 the exit conduit **25** is shown as connected to a spray device **145** in the upper interior of a collection vessel **150**. The mixed product is sprayed and additionally mixed in this way and in passing through a pump **151** shown as disposed in a conduit **152** connected to the inlet passage **72**. The pump **151** can alternatively be positioned in the exit conduit **25** or another pump can be therein positioned to facilitate the recirculation. There can be some degree of aeration in the collection vessel **150**. In addition, the liquid stream passing through the vibration zone of the mixing chamber **33** can be further aerated by a gaseous medium used to induce the vibration or further hydrated by the condensate particles previously mentioned.

As an example of the invention when employed in the manufacture of cream substitutes, an apparatus as shown approximately full size in FIG. 2 was used under the following conditions. A mixture of a vegetable or nut oil (about 4–30%), water (about 60–65%), sugar (about 7%) and a fraction of a percent of an emulsifying agent selected from the class of mono-, di- and tri-glycerides was circulated through the system of FIG. 1 for a period of five minutes, employing steam at a temperature of about 360° F. as the gaseous medium for effecting vibration of the segments of the vibratory member **60**. The resulting product had a particle size averaging 10 microns or less and compared with a product produced by circulating the same mixture through the same equipment for 45 minutes in the absence of the invention in the recirculation line.

Various changes and modifications can be made without departing from the spirit of the invention as defined in the appended claims.

I claim as my invention:

1. A mixing apparatus comprising: a housing including a chamber with an inner wall; a nozzle including concentric members providing a narrow annular orifice therebetween spaced from said wall and discharging into said chamber in a given direction; means for delivering to said nozzle a high-pressure gaseous medium discharging from said orifice in said direction as a high-velocity jet; a tubular cylindrical vibratory member facing in a direction substantially opposite to said given direction and having a forward edge facing but spaced from said annular orifice, said forward edge and said annular orifice being in axial alignment, said forward edge being positioned to be contacted by said annular stream to be vibrated thereby; and means for circulating a stream of liquid material into and from said chamber through said vibratory member to be mixed by the vibrations thereof.

2. A mixing apparatus as defined in claim 1 in which said nozzle comprises an outer member having a conical surface and a substantially cylindrical surface extending from said conical surface toward said forward edge of said vibratory member, and an inner member movable relative to the outer member and having a mating conical surface and a substantially cylindrical surface extending from said conical surface toward said forward edge of said vibratory member, said substantially cylindrical surfaces being spaced to define said narrow annular orifice therebetween.

3. A mixing apparatus as defined in claim 1 in which said tubular vibratory member contains a plurality of peripherally-spaced slots extending from said forward edge substantially parallel to the axis of such tubular member and dividing the forward portion of such member into at least two reed-like cylindrical segments separated by said slots and capable of independent vibration, each of said

reed-like segments having an end facing said narrow annular orifice.

4. A mixing apparatus comprising: a tubular housing; an outer annular member dividing the interior of said tubular housing into a mixing chamber and an inlet chamber; an inner annular member within said outer member and cooperating therewith in defining a narrow annular orifice interconnecting said inlet and mixing chambers; means for delivering a gaseous medium under pressure to said inlet chamber, said orifice producing a high-velocity annular stream directed into said mixing chamber in the direction of the axis of said tubular housing; a base member in said tubular housing at a position downstream from said orifice; a tubular vibratory member having a rear portion with an inner surface positioned by said base member and a forward portion terminating in a forward edge positioned in the path of said annular stream to be vibrated thereby; conduit means for delivering a liquid stream to said mixing chamber to flow past said forward portion, the vibrations thereof intermixing the components of said liquid stream and mixing same with said gaseous medium to produce a mixed product; and exit means for withdrawing at least a portion of said mixed product from said mixing chamber from a position within said rear portion of said tubular vibratory member adjacent the inner surface of said rear portion.

5. A mixing apparatus comprising: a tubular housing providing a chamber with an inner wall and containing an inlet end and a discharge end; a nozzle at the inlet end including concentric spaced members providing a narrow annular orifice therebetween spaced from said inner wall and discharging into said chamber; a sleeve member with a forward end positioned in the chamber adjacent the discharge end and including an outer wall in sealing engagement with the inner wall of the chamber; a cylindrical vibratory member mounted on the forward end of the sleeve member directed toward the orifice and spaced from the inner wall of the chamber; means for delivering a high-pressure gaseous medium to said nozzle for discharge into said chamber through the orifice to vibrate the cylindrical vibratory member; means for introducing a liquid material into the chamber between the orifice and the vibratory member to be mixed by the vibrations of the latter; and passage means between the interior of the sleeve and the discharge end of the chamber for withdrawing the result product.

6. A method of mixing the components of a liquid stream and a gaseous stream by the use of a vibratory member terminating in an edge, which includes the steps of: forming the gaseous stream into a high velocity jet directed toward said edge to vibrate the same at ultrasonic frequency; delivering the liquid stream to the zone of such vibration and employing the vibration to aid in mixing the components of said liquid and gaseous streams

to produce a mixed product, said gaseous stream comprising steam and the liquid stream being at a temperature lower than said steam to condense the same into minute particles forming a part of said mixed product, the condensing of the steam heating the liquid stream and aiding the mixing by increasing the cavitation effect produced by the ultrasonic vibrations; and withdrawing such mixed product continuously from the zone of said vibration.

7. A method of mixing the components of a liquid stream and a gaseous stream utilizing a vibrating member which terminates in an edge, including the steps of: directing the gaseous stream as a high velocity jet toward said edge to vibrate the same; delivering the liquid stream to the zone of such vibration and employing the vibration to aid in mixing the components of said liquid and gaseous streams to form a product, the temperature of the incoming liquid stream being lower than the vaporization temperature of the gaseous stream to cause the latter to condense in said zone of vibration in a percussive collapse which further aids in the mixing of said components; and withdrawing such product from the zone of vibration.

8. In a method of mixing together the components of a liquid stream and a gaseous stream utilizing a vibrating member, the step of delivering the liquid stream to the zone of vibration at a temperature lower than the vaporization temperature of the gaseous stream to reduce the temperature of the latter and cause it to condense with a percussive collapse and thereby aid in the mixing of said components.

9. In a method of mixing together the components of a liquid stream and a stream of high pressure steam utilizing a vibrating member, the step of delivering the liquid stream to the zone of vibration at a temperature lower than the vaporization temperature of water to reduce the temperature of the steam and cause it to condense with a percussive collapse and thereby aid in the mixing of said components.

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,081,979 March 19, 1963

Ernest E. Lindsey

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 7, line 28, for "and containing" read -- , said chamber having --; lines 32 and 33, strike out "with a forward end"; line 34, for "and including" read -- , said sleeve member having a forward end and having --; line 46, for "result" read -- resulting --.

Signed and sealed this 15th day of October 1963.

(SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

EDWIN L. REYNOLDS
Acting Commissioner of Patents