United States Patent

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[54] **APPARATUS FOR PRODUCING BUBBLES OF VERY SMALL, MICROSCOPIC SIZE**
7 Claims, 5 Drawing Figs.

[52] **U.S. Cl.** **261/122,** 210/220
[51] **Int. Cl.** **C02c 1/02,** B01f 3/04, B01f 5/04
[50] **Field of Search** 261/121, 122, 124; 210/14, 15, 220

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ABSTRACT: An apparatus is provided for producing bubbles of 5 to 10 micron size in a liquid by a sparger inside a pipe wherein the clearance between the sparger and the pipe is maintained in relation to the velocity of the liquid passing over the sparger such that the height of the laminar sublayer in the liquid is maintained less than 10 microns. The bubbles are produced by pressure perturbations in the turbulent layer above the laminar sublayer such that as gas issues from the sparger through the laminar sublayer the pressure perturbations will snap off the bubbles before they can grow larger than 10 microns in size. A narrow annular passageway is provided between the sparger and pipe. This annular passageway is provided with an increasing taper in the downstream direction of the liquid stream. The taper increase in flow cross section produces a corresponding pressure increase in the liquid stream in the direction of flow which is sufficient to compensate for the pressure drop due to friction losses. The liquid flow pressure over the surface of the sparger is maintained uniform. A stream lined tail cone portion is attached to the downstream end of the sparger. A convergence in the inner wall of the shell member in juxtaposition with the tail cone portion forms an exit passage of reduced cross section for the liquid stream. A handwheel is attached to the sparger for axially displacing the sparger relative to the shell member for adjusting the clearance space between the tail cone portion and the exit passage.

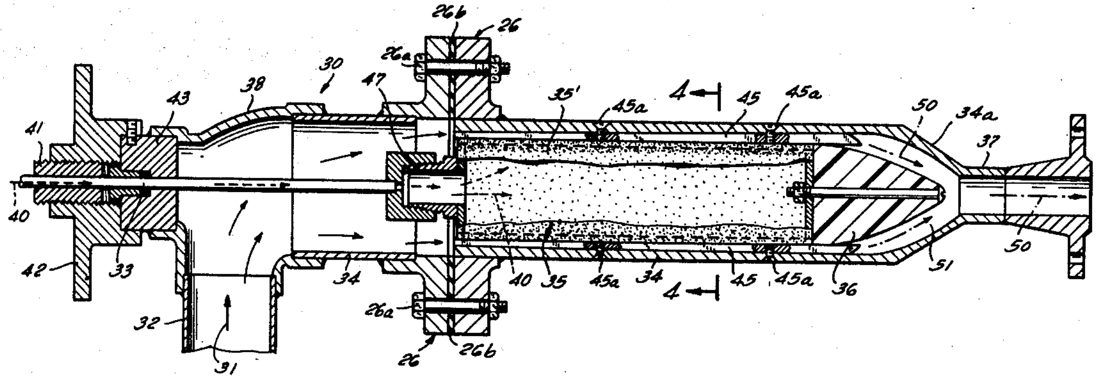


FIG. 1

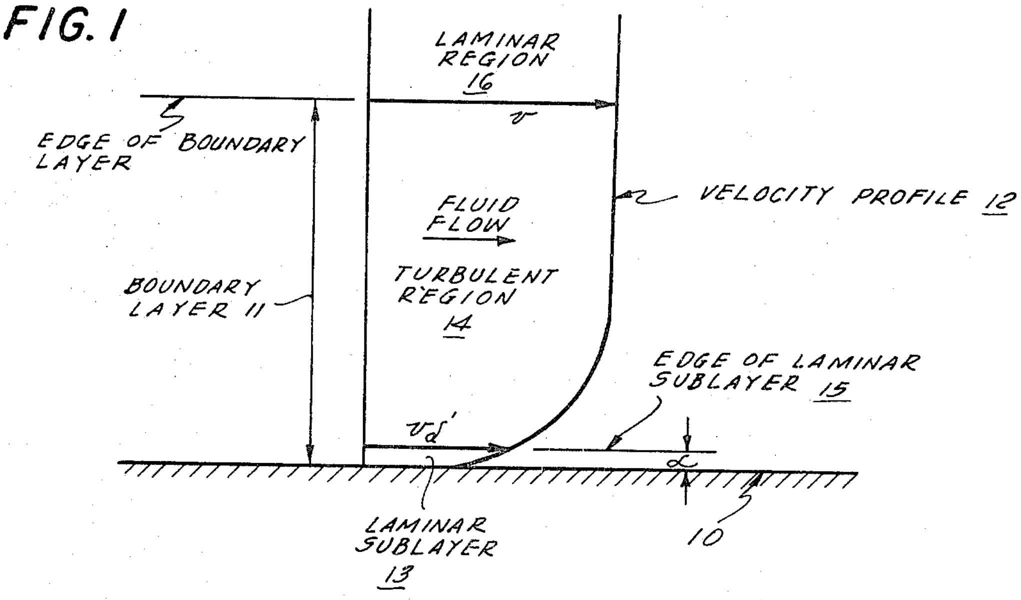
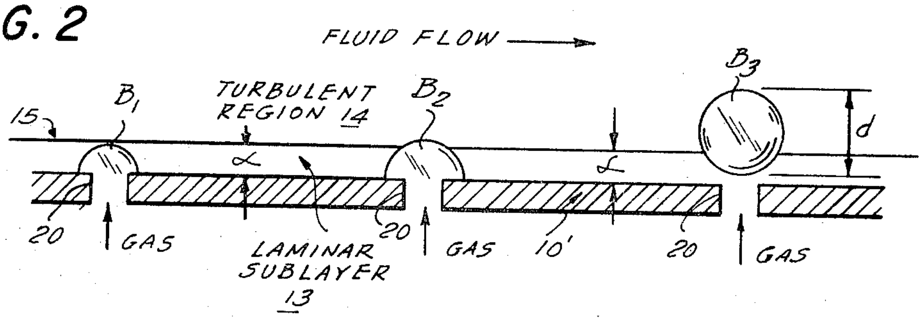

LAMINAR REGION 16
v
EDGE OF BOUNDARY LAYER
VELOCITY PROFILE 12
FLUID FLOW
BOUNDARY LAYER 11
TURBULENT REGION 14
EDGE OF LAMINAR SUBLAYER 15
v_{d}'
α
LAMINAR SUBLAYER 13
10

FIG. 2


FLUID FLOW
B_3
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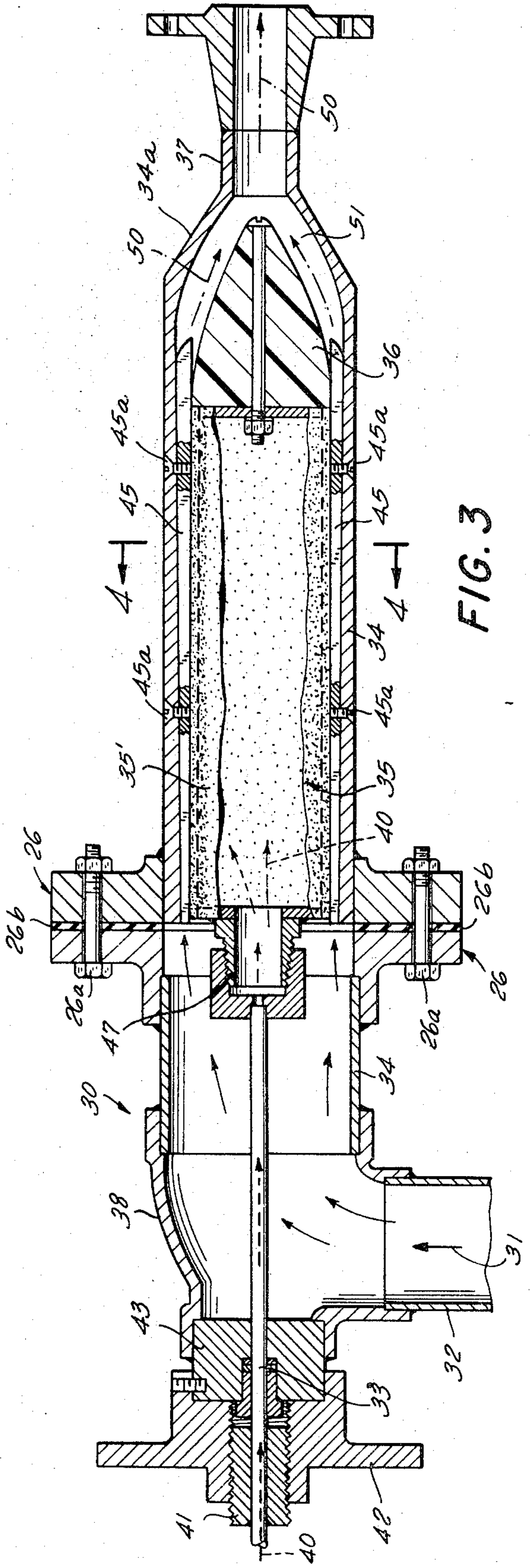

FIG. 3

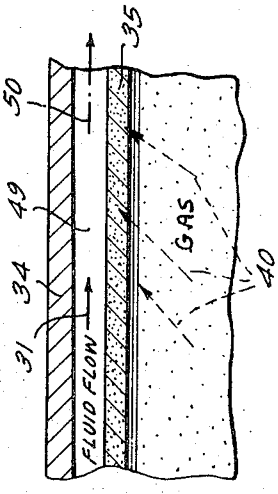

FIG. 5

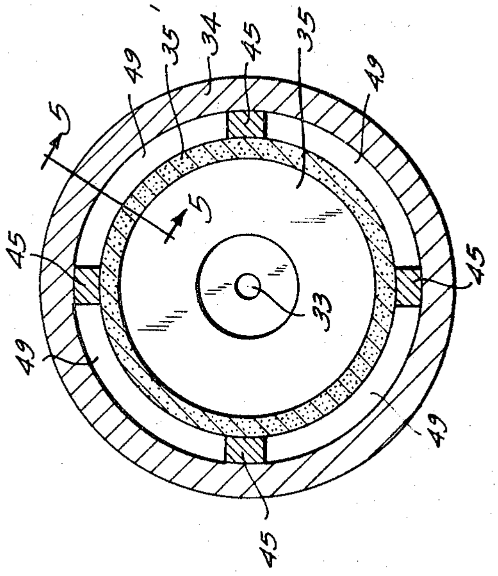

FIG. 4

APPARATUS FOR PRODUCING BUBBLES OF VERY SMALL, MICROSCOPIC SIZE

This invention is directed to means for producing large, homogeneous quantities of gas bubbles of microscopic size on the order of 5—10 microns in diameter. The invention finds particular utility in applications requiring the intermixture of gases with liquids; for example, sewage treatment, water chlorination, petroleum processing, aeration, oxygenation, and other processes wherein a gas-phase material is to be dissolved or dispersed into a liquid medium medium.

The present invention utilizes the distinctive boundary layer characteristics of turbulent fluid-flow phenomena in order to achieve the consistent production and dispersion of large, homogeneous quantities microscopically sized bubbles (hereinafter sometimes referred to as microbubbles). The means of the present invention differs primarily from prior art techniques for the production of bubbles in that (1) dense clouds comprised exclusively of vary large numbers of bubbles of microscopic size, on the order of 5—10 microns in diameter, are consistently produced and are dispersed into the fluid medium without coalescence, and (2) after certain critical flow field conditions are attained, the production of the microbubbles according to the present invention proceeds virtually independently of increasing gas flow rate or fluid velocity. In order to better distinguish the manner in which the present invention differs from that of prior processes, the nature of some of the commonly used techniques for producing gas bubbles will be briefly reviewed.

In the airstone principle, which is an extension of the technique of blowing bubbles through a plurality of capillary tubes, the gas stream is forced through a porous surface having a large number of flow passages of very small diameter. The buoyant forces of the liquid medium above the airstone is utilized as the sole mechanism for detaching the bubbles from the surface. The size of the resultant bubbles, which is related to the flow rate of the gas stream, is not exceptionally small nor homogeneous, and it is rare for bubble sizes less than 1,000 microns in diameter to produced.

In order to improve the mechanism of bubble production by the airstone principle and to obtain bubbles of smaller size, it has been conventional to impart a flow of relatively low velocity to the fluid medium in order to detach the bubbles away from the gas outlets and into the liquid. In such a system the viscous forces of the fluid flow shear the bubbles off of their gas outlets at a premature size, and the resultant bubble size is then a function of both the gas and liquid flow rates. However, as first recognized in the present invention, unless certain critical flow conditions are present in the fluid stream, homogeneous clouds of gas bubbles of microscopic size will not be consistently produced.

In the present invention, a turbulent boundary layer is established in a liquid flow passing over a suitable bubble-producing surface, which may be in the form of a porous plate, cylinder, or the like having a large number of flow passages of sufficiently small diameter to permit production at the interface of bubbles of micron size. The liquid flow is made sufficiently turbulent such that an intense velocity gradient is present at the surface of the gas bubble. This produces pressure perturbations around the bubble which are of the magnitude necessary to overcome the relatively high interface forces securing the bubble to the surface. Detachment of the bubbles from the surface then occurs as a result of forces applied normal to the surface as the bubble responds to the random but highly frequent pressure variations in the turbulent boundary layer. However, and most importantly, in order to ensure the creation of bubbles of the desired microscopic size, it is critical that the laminar sublayer of film, which exists in the boundary layer of the liquid flow between the turbulent stream and the bubble-producing surface, have a thickness which is approximately equal to, but somewhat less than, the diameter of the desired microbubbles to be produced.

It is characteristic of the present invention that, once suitable conditions have been established for the production of microbubbles by the attainment of a satisfactorily high flow velocity in the liquid stream, the flow rate of the introduced gas may be increased independently without affecting the size of the bubbles produced. Conversely, once the conditions of microbubble production are established, any increase in the velocity of the liquid flow similarly will not substantially affect the size or rate of production of microbubbles.

Control of the thickness of the laminar sublayer in the turbulent boundary layer of the fluid flow is the crucial parameter in determining the ultimate size of the produced bubbles. From empirical tests it has been determined that the thickness of this laminar sublayer should preferably be on the order of 0.9 of of the diameter desired for the resultant gas bubbles. While the growing bubble remains entirely in this region of laminar flow, which exists between the surface of the bubble-producing gas outlets and the turbulent boundary layer of the fluid, it is subjected only to viscous shear stresses; however, once the hemisphere of the growing bubble enters into the region of the turbulent boundary layer, the bubble is then subjected to the severe and irregular pressure variations, normal to the surface wall, which are characteristic of turbulent flow and produced by the transfer of fluid masses between adjacent layers. These pressure perturbations serve to snap off the bubble from its gas outlet before further growth permits it to protrude to any substantial depth into the turbulent boundary layer.

In an exemplary embodiment of the present invention, apparatus has been provided for accomplishing the desired microbubble production by utilizing the boundary layer phenomena described above. Means are provided in the apparatus for controlling the flow rate of liquid past the bubble-producing surface in order to establish the desired turbulent boundary layer and for regulating the thickness of the associated laminar sublayer. Once the predetermined critical flow conditions are established, the apparatus will then produce and disseminate into the liquid stream dense, homogeneous clouds of very fine, microscopically sized gas bubbles.

It is therefore a principal objective of the present invention to provide apparatus for producing large, homogeneous quantities of extremely small, microscopically sized gas bubbles.

It is another objective of the present invention to provide apparatus for improving the intermixing of gases with liquids.

It is a characteristic feature of the present invention that a turbulent fluid flow stream is utilized to produce gas bubbles of extremely small size on the order of 5—10 microns in diameter.

It is another distinctive feature of the present invention that the size of the resultant gas bubbles is on the same order of magnitude as the thickness of the laminar sublayer present in the boundary layer of the turbulent fluid flow.

It is an important advantage that the size of the microscopically small bubbles produced by the process of the present invention is independent of both the gas flow rate and the velocity of the fluid stream, as long as certain boundary layer conditions, conditions are maintained in the fluid flow.

The foregoing and other objectives, features, and advantages of the present invention will be more readily understood upon consideration of the following detailed description of the invention, taken in conjunction with the accompanying drawings.

FIG. 1 is a schematic diagram illustrating the boundary layer conditions present in the flow of a turbulent stream of liquid over a flat, smooth surface.

FIG. 2 is a schematic diagram, similar to FIG. 1, showing the progressive growth of bubbles from gas outlets in a porous plate.

FIG. 3 is a front sectional view, partially broken away, of an exemplary embodiment of apparatus for producing microbubbles in accordance with the present invention.

FIG. 4 is a cross-sectional view, taken along the lines 4–4 in FIG. 3.

FIG. 5 is a sectional view, taken along the lines 5–5 in FIG. 3.

Referring now to FIG. 1, which will be useful for background purposes in understanding the fluid flow phenomenon utilized in the practice of the present invention, there is shown a velocity profile diagram of the boundary layer conditions which are present in the flow of a turbulent stream over a flat, smooth plate or boundary wall **10**. As is presented by the curve **12**, the velocity of the fluid at points along a vertical section of the flow is zero at the surface of the boundary wall **10** and increases asymptotically to a constant value v in the laminar region **16** outside the turbulent boundary layer **11**.

The fluid in the region **13** of the boundary layer immediately adjacent to the boundary wall **10** moves very slowly in parallel layers, and there is no transfer of fluid masses between adjacent layers in the flow. In this region **13**, known as the laminar sublayer or film, the fluid flow is laminar in nature, its velocity gradient follows a linear relationship with increasing distance from the boundary wall **10**, and the pressure differential is small and uniform within this sublayer.

However, at a certain distance α away from the boundary wall **10**, a transition is made into the turbulent region **14** where there is a relatively high velocity flow with a continuous intermixture of fluid masses and transfer of momentum between adjacent layers. While, in this region **14**, the fluid mass as a whole moves downstream with a steady average velocity, there are sharply fluctuating velocity components occurring in all directions. The flow pattern is unsteady, full of eddies, and apparently without any mathematically expressible regularity. These irregular and abrupt velocity fluctuations produce corresponding severe pressure variations within the turbulent region **14** of the fluid flow.

It should be recognized that the transition or interface **15** between the laminar sublayer **13** and the turbulent region **14** of the boundary layer is not in actuality a sharply defined edge, as indicated in the diagram; however, for purposes of simplifying the explanation of the invention the assumption will be made that the transition from laminar to turbulent flow is made abruptly at the edge **15**. Using a generally accepted approach in the art, i.e., the Karman-Prandtl equation for the velocity distribution in turbulent flow near smooth boundaries, the transition line **15** may be nominally defined by the intersection of two curves: a straight line curve representing the essentially linear nature of the velocity gradient in the laminar sublayer **13**, and a logarithmic curve representing the more complex relationship between flow velocity and distance from the boundary wall in the turbulent region **14**. (For a detailed description of the flow phenomena occurring in a turbulent boundary layer, as well as the mathematical treatment thereof, reference may be made to any one of a number of standard treatises in the field of fluid dynamics, such as, for example, Rouse, Elementary Mechanics of Fluids (Second Edition), Chapter VII, Wiley and Sons, New York, 1950.) Thus, as a generalization, it may be considered that flow in the fluid stream on the near side of the transition line **15** at distances of α or less away from the boundary wall **10** is laminar; while, on the other side of the line, the flow at distances greater that α is essentially turbulent in nature.

In FIG. 2 the fluid flow, schematically represented in FIG. 1, is now shown as passing over a porous plate or boundary wall **10 10'** provided with a number of minute openings **20**. These openings **20** act as outlets for a gas stream supplied under pressure to the underside of the porous plate **10'**.

As gas emerges from each of the outlets **20** and is introduced to the fluid streams, growing bubbles such as B_1 are formed on the upper surface of the plate **10'**. During the time that the growth of the gas bubble B_1 is relatively small and contained within the laminar sublayer **13** which exists in the region immediately adjacent the surface of the plate **10'**, the bubble will be subjected to only moderate shear and buoyant forces tending to detach it away from its outlet **20**. If, for example, the fluid flow is comprised of water or other suitable liquid, the adhesive forces of surface tension produced at the gas-liquid interface of the bubble will be more than sufficient to prevent its detachment during this time.

However, once the hemisphere of the growing bubble protrudes beyond the relatively tranquil flow of the laminar sublayer **13** and into the turbulent region **14** of the flow boundary layer, the bubble, shown at B_2, is then subjected to extremely strong detachment forces which are normal to the surface **10'** and produced by the severe pressure fluctuations present in this latter region. These forces, which are of much greater intensity than those encountered while the growth of the bubble was confined entirely to the laminar sublayer **13**, pluck off the bubble, now shown as B_3, from its outlet **20** and thrust it into the flowing fluid stream before any significant amount of further growth is permitted to occur. Thus, the completed bubble B_3 attains, at the instant of detachment from the surface **10'**, a size dimension d which is on the same order of magnitude as the thickness α of the laminar film **13**. Since the laminar film in a turbulent boundary layer is very thin and on the order of only a few microns in thickness, the size of the detached bubble B_3 is similarly quite small, typically being in the range of 5 to 10 microns in diameter.

As the thickness α of the laminar sublayer **13** remains constant with time and does not vary significantly along the direction of turbulent flow over the boundary wall **10'**, all of the completed bubbles B_3 formed by the above-described process will be of substantially the same diameter d, thus resulting in the production of a homogeneous cloud of microscopically sized gas bubbles. Furthermore, since the thickness α of the laminar sublayer **13** decreases only slightly with increasing flow velocity in the turbulent boundary layer **11**, any change in the velocity of the fluid stream will not substantially affect the size or rate of production of the resulting microbubbles, so long as turbulent flow conditions are maintained. Similarly, since the size of the completed bubbles B_3 at the point of detachment from the boundary wall **10** is dependent primarily on the thickness α of the laminar film **13**, variation of the flow rate of the gas introduced into the fluid stream via outlets **20** will not produce any corresponding change in the size of the resulting microbubbles.

The comparative insensitivity of the resultant bubble size to large changes in the fluid and/or gas stream flow rates is a characterizing feature of the present process which dramatically differentiates it from the prior art methods of bubble production discussed previously. This distinctive aspect of the process permits a ready determination to be made as to whether the proper flow conditions have been established in a system for the production of microbubbles according to the principles of the present invention.

FIGS. 3—5 illustrate an exemplary embodiment of an apparatus which has been constructed for producing microbubbles in accordance with the present invention.

The apparatus **30** comprises a cylindrical sparger portion **35** having a porous surface **35'** with an average pore diameter of 5 to 10 microns—a pore size which is slightly less than the size of th the resulting microbubbles to be produced. The sparger **35** is mounted inside an outer shell member **34**, the clearance between which is tapered inward toward the left-hand end of the apparatus for reasons that will hereinafter be explained. Of course, either the inner wall of the shell **34**, as shown in FIG. 3, or the outer surface **35'** of the sparger **35**, may be configured to have the required taper. For construction and mounting purposes, the shell member **34** is in two parts flanged together at **26** with connecting bolts **26*a*** and sealing gasket **26*b***. A set of longitudinally extending guide vanes **45**, attached to the inner wall of the shell member **34** by fasteners **45*a***, maintain the cylindrical sparger **35** in a concentric relationship inside the shell member with a small tapered passageway **49** therebetween whose cross section, as shown in FIG. 4, is in the form of a segmented annular ring.

With fluid and gas flows both proceeding from left to right in the diagram of FIG. 3, the left-hand, or upstream, end of the sparger **35** is joined through a connecter **47** to a gas inlet pipe **33**. The left-hand end of the shell member **34** is connected to a joint **38** threaded with a handwheel assembly **41, 42, 43** which enables the sparger **35** to be adjustably positioned along the axis of the shell. Also at the upstream end of the apparatus, a fluid inlet pipe **32** is connected at right angles through joint **38** to the shell member **34**.

At the right-hand, or downstream, end of the apparatus the sparger **35** is terminated in a hydrodynamically streamlined tail cone portion **36**, and the shell member **34** converges at **34*a*** into a discharge line connecter **37**. Thus, by longitudinal displacement of the sparger **35** through operation of the handwheel **42**, the size of the flow passage **51** between the tail cone **36** and the converging walls **34*a*** of the shell member may be adjusted, similar to a valve, to provide a flow control point downstream of the sparger **35** of for reasons which will be shortly explained.

As shown in FIG. **3**, it the fluid flow from the inlet pipe **32** (represented by the solid arrows **31**), after it enters the apparatus at joint **38** and makes a right-angled turn, then passes into the narrow annular passageway **49** which surrounds the body of the sparger cylinder **35**. Due to this severe constriction in the cross-sectional area of the fluid flow as it travels through the annular passageway **49**, boundary turbulent shear flow will be produced in the fluid stream (assuming the fluid entering at inlet pipe **32** is of a suitable velocity).

As the turbulent flow proceeds through the narrow annular passage **49**, it is intermixed, as shown in FIG. **5**, with the gas stream from the inlet line **33** (represented by the dashed arrows **40**) at the boundary wall presented by the porous surface **35'** of the sparger. The combined fluid-gas flow stream (represented by the dotted-dashed arrows **50**) then emerges at the downstream end of the apparatus **30** passing through the clearance space **51** around the tail cone portion **36** of the sparger and thereafter into the discharge line connecter **37** from where it is exhausted.

The purpose of providing a taper in the annular passageway **49** is to maintain the flow pressure constant along the length of the cylindrical body of the sparger **35**. If the fluid-gas differential pressure in the flow passing over the porous surface **35'** of the sparger body is not kept uniform, there will be the possibility that the gas will be injected into the fluid flow at too great velocity at some points, or that, due to excessive fluid pressure, fluid will seep into the porous sparger at other points. Since the gas flow **40** inside the hollow sparger body is at essentially a constant pressure throughout it is therefore necessary to maintain constant as well the fluid pressure on the outside of the sparger, in order that a uniform fluid-gas pressure differential exist along the length of the interface boundary surface **35'**.

In order to counteract the pressure drop in the fluid flow caused by friction as the fluid travels along the length of the sparger body, the cross-sectional area of the fluid flow is gradually increased in the downstream direction by means of the taper so that the consequent decrease in fluid velocity, due to the enlarging cross section, produces a pressure increase which just compensates for the pressure decrease due to friction losses. (The amount of the taper which must be provided in the passageway **49** to achieve the desired degree of compensation can be readily calculated by known fluid dynamics techniques, taking into account the parameters of the flow system.)

In operation, with an illustrative set of flow parameters, the required turbulent flow conditions for the production of microbubbles according to the present process may be established in the apparatus by the adjustment of the sparger cylinder **35** for optimum pressure and flow rate characteristics in the following manner: A high fluid flow rate **31**, on the order of 100 gallons per minute or greater, is established through the apparatus **30** with the sparger cylinder **35** located in the maximum upstream position (i.e., to the left as shown in FIG. **3**). By means of the adjustment provided by the handwheel **42**, the sparger **35** is then slowly moved in the downstream direction (i.e., toward the right in FIG. **3**), moving the tail cone **36** closer to the converging walls **34*a***. The constriction of the fluid flow in the tail cone region **51** will, in much the same manner as a valve, cause the flow of fluid **31** passing over the surface **35'** of the sparger body to decrease, while the pressure head slowly builds up.

The placement of the low control point, which is provided by the valve action in the tail cone region **51**, at a location downstream of the sparger body **35** is an important feature of the sparger design. If a flow constriction, having a smaller cross-sectional area than the minimum clearance area in the tapered annular passageway **49**, is not provided downstream of the sparger body, then a differential pressure drop will occur in the fluid flow somewhere along the surface **35'** of the sparger. This differential pressure drop will, under certain circumstances, move rapidly back and forth along the sparger surface **35'** and will completely disrupt the formation of microbubbles according to the disclosed process. By movement of the sparger along the axis to control the area of constriction in the tail come region **51**, and thereby causing the required pressure drop at a point downstream of the sparger body **35**, a constant pressure along the entire surface **35'** of the sparger body may be easily maintained.

As the pressure head in the fluid flow begins to increase sharply due to the constricted flow at the tail cone region **51**, reaching 75 p.s.i. or so, the gas stream is then induced into the center of the porous sparger **35**, via the inlet line **33**, at a flow rate on the order of 600 standard cubic feet per hour. With the position of the sparger thus adjusted to produce a turbulent boundary layer over the surface of the cylinder, the bubbles of gas forming at the surface pores **35'** or of the sparger **30** will be detached and swept into the fluid as soon as they project beyond the laminar sublayer of the flow, thus producing microbubbles in accordance with the process disclosed earlier. The gas flow **40** may thereafter be increased to any desired rate without affecting the production of microbubbles, the flow rate of gas being limited only by the crowding of attached bubbles during their formation on the porous surface **35'** of the sparger **35**.

The narrow tapered passageway over the sparger body, together with the valvelike action provided by the axial adjustment of the sparger which establishes a flow control point for pressure head control downstream of the sparger body, enables the production of gas bubbles of microscopic size in the sparger apparatus **30** without the need for any external adjustment of the liquid or gas flow rates. The only limiting condition on the operation of the apparatus is that the fluid flow rate must exceed a certain minimum value corresponding to the establishment of the necessary fluctuating turbulent flow field over the porous cylindrical body **35'** of the sparger so that microbubbles will be produced.

The terms and expressions which have been employed here are used as terms of description and not of limitation, and there is no intention, in the use of such terms and expressions, of excluding equivalents of the features shown and described, or portions thereof, it being recognized that various modification are possible within the scope of the invention claimed.

I claim:

1. An apparatus for producing large homogeneous quantities of gas bubbles of microscopic size of 10 microns or less in diameter, comprising:

a. a bubble-producing surface having a plurality of gas outlets of smaller diameter than that desired of said resultant bubbles;

b. a surface opposing said bubble-producing surface and forming therewith a passageway for liquid flow;

c. means for passing a liquid flow therethrough at positive pressure;

d. means for adjusting the velocity of said liquid flow in relation to said passageway to establish a turbulent boundary layer therein, said boundary layer being comprised of a turbulent region having severe and irregular velocity fluctuations therein and a laminar sublayer having a regular linear velocity gradient, said sublayer being situated beneath said turbulent region and adjacent said bubble-producing surface and having a thickness comparable to the diameter desired of said resultant bubbles, said surfaces diverging in the direction of said flow to compensate for friction losses in said flow to maintain fluid pressure on said bubble-producing surface constant over its length; and

e. means for supplying a gas stream to the outlets on said bubble-producing surface, whereby gas bubbles forming on said surface are detached therefrom and carried into said liquid flow when the size of said forming bubbles begins to exceed the thickness of said laminar sublayer and to project into said turbulent region.

2. The apparatus set forth in claim **1** further including means for maintaining uniform the liquid-gas pressure differential at said bubble-producing surface by compensating for frictional losses in said liquid flow thereover.

3. The apparatus set forth in claim **1** further including means for controllably constricting said liquid flow at a position immediately downstream of said bubble-producing surface, thereby to prevent the creation of a differential pressure drop in said fluid flow at a location on said surface.

4. The apparatus set forth in claim **1**, further including means for providing a flow control point in said liquid flow at a location downstream of said bubble-producing surface, comprising:

a. an end portion on said bubble-producing surface;
b. A convergence in said opposing surface in juxtaposition with said end portion to form an exit passage of reduced area for said liquid flow; and
c. means for displacing said bubble-producing surface along a line parallel to said liquid flow relative to said opposing surface for adjusting the size of the clearance space between said end portion and said exit passage.

5. An apparatus for producing large homogeneous quantities of gas bubbles of microscopic size of 10 microns or less in diameter, comprising:

a. a hollow sparger having a porous, cylindrical surface with an average pore diameter of 5 to 10 microns in diameter;
b. cylindrical shell member coaxial with said sparger and having an inner wall greater size;
c. the arrangement of said sparger surface and the inner wall of said shell member forming an annular, narrow passageway therebetween;
d. means for supplying a pressurized stream of gas to the inside of said sparger for dispersion to the outside through the surface pores thereof; and
e. means for directing a liquid stream into said passageway at a pressure of at least 75 p.s.i. to establish a turbulent boundary layer over the surface of said sparger, wherein said annular passageway is provided with an increasing taper in the downstream direction of said liquid stream, the tapered increase in flow cross section producing a corresponding pressure increase in said liquid stream in the direction of flow which is sufficient to compensate for the pressure drop due to friction losses, whereby the liquid flow pressure over the surface of said sparger is maintained uniform.

6. An apparatus for producing large homogeneous quantities of gas bubbles of microscopic size of 10 microns or less in diameter comprising:

a. a hollow sparger having a porous, cylindrical surface with an average pore diameter of 5 to 10 microns in diameter;
b. a cylindrical shell member coaxial with said sparger and having an inner wall of greater size;
c. the arrangement of said sparger surface and the inner wall of said shell member forming an annular, narrow passageway therebetween;
d. means for supplying a pressurized stream of gas to the inside of said sparger for dispersion to the outside through the surface pores thereof;
e. means for directing a liquid stream into said passageway at a pressure of at least 75 p.s.i. to establish a turbulent boundary layer over the surface of said sparger; and
f. means for providing a flow control point in said liquid stream at a location downstream of said sparger surface, said means comprising, a streamlined tail cone portion attached to the downstream end of said sparger, a convergence in the inner wall of said shell member in juxtaposition with said tail cone portion to form an exit passage of reduce cross section for said liquid stream, and means for axially displacing said sparger relative to said shell member for adjusting the size of the clearance space between said tail cone portion and said exit passage.

7. An apparatus for producing large homogeneous quantities of gas bubbles of microscopic size 10 microns or less in diameter, comprising:

a. a hollow sparger having a porous, cylindrical surface with an average pore diameter of 5 to 10 microns in diameter;
b. a cylindrical shell member coaxial with said sparger and having an inner wall of greater size;
c. the arrangement of said sparger surface and the inner wall of said shell member forming a generally annular, narrow passageway therebetween;
d. means for supplying a pressurized stream of gas to the inside of said sparger for dispersion to the outside through the surface pores thereof;
e. means for directing a liquid stream into said passageway at a pressure of at least 75 p.s.i. to establish a turbulent boundary layer over the surface of said sparger; and
f. means for providing a flow control point in said liquid stream at a location downstream of said sparger surface, said means comprising:
   i. an end portion on said sparger;
   ii. a convergence in the inner wall of said shell member in juxtaposition with said end portion to form an exit passage of reduce cross section for said liquid stream; and
   iii. means for axially displacing said sparger relative to said shell member for adjusting the size of the clearance space between said end portion and said exit passage.