(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: 0 364 654 A2

(12) EUROPEAN PATENT APPLICATION

(21) Application number: 89103088.4

(51) Int. Cl.5: B03D 1/24

(22) Date of filing: 22.02.89

(30) Priority: 21.10.88 US 260813

(43) Date of publication of application: 25.04.90 Bulletin 90/17

(84) Designated Contracting States: DE ES FR GB IT SE

(71) Applicant: THE DEISTER CONCENTRATOR CO., INC.
901 Glasgow Avenue
Fort Wayne Indiana 46801(US)

(72) Inventor: Zipperian, Donald E.
5380 East Placita Casa Rio
Tucson Arizona 85718(US)

(74) Representative: Strasse, Joachim, Dipl.-Ing. et al
Eisenführ, Speiser & Strasse
Zweibrückenstrasse 17
D-8000 München 2(DE)

(54) Method and apparatus for generating microbubbles in froth flotation mineral concentration systems.

(57) A method and apparatus for generating microbubbles in a flowing liquid stream for use in a froth flotation system. The system utilizes a microbubble generator having a tubular housing with an inlet end and an outlet end. Located coaxially within the housing is an inner member with an elongated exterior cylindrical surface. A porous tubular sleeve is mounted between the housing and the inner member coaxially therewith to define with the cylindrical interior surface of the housing an elongated air chamber of annular cross section. The porous sleeve also has a cylindrical inner surface that defines with the exterior surface of the inner member an elongated liquid flow chamber of thin, annular cross section. An aqueous liquid is supplied to the liquid flow chamber at a relatively high flow rate and air under pressure is supplied to the air chamber so that air is forced radially inwardly through the porous sleeve to be diffused in the form of microbubbles in the flowing stream.

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METHOD AND APPARATUS FOR GENERATING MICROBUBBLES IN FROTH FLOTATION MINERAL CONCENTRATION SYSTEMS

BACKGROUND OF THE INVENTION

This invention relates to the separation of minerals in finely comminuted form from an aqueous pulp by froth flotation process, and especially to a froth flotation system with an improved means for introducing the gaseous medium in the form of minute bubbles into the liquid flotation column. More particularly, the invention relates to a device for generating gas bubbles in a flowing stream of aqueous liquid and delivering the bubble containing stream to the flotation column.

Commercially valuable minerals, for example, metal sulfides, apitictic phosphates, and the like, are commonly found in nature mixed with relatively large quantities of gangue materials. As a consequence, it is usually necessary to beneficiate the ores in order to concentrate the mineral content. Mixtures of finely divided mineral particles and finely divided gangue particles can be separated and a mineral concentrate obtained therefrom by widely used froth flotation techniques.

Froth flotation involves conditioning an aqueous slurry or pulp of the mixture of mineral and gangue particles with one or more flotation reagents which will promote flotation of either the mineral or the gangue constituents of the pulp when the pulp is aerated. The conditioned pulp is aerated by introducing into the pulp minute gas bubbles which tend to become attached either to the mineral particles of the gangue particles of the pulp, thereby causing one category of these particles, a float fraction, to rise to the surface and form a froth which overflows or is withdrawn from the flotation apparatus.

The other category of particles, a non-float fraction, tends to gravitate downwardly through the aqueous pulp and may be withdrawn at an underflow outlet from the flotation vessel. Examples of flotation apparatus of this type are disclosed in U.S. patents Nos. 2,753,045; 2,758,714; 3,298,519; 3,371,779; 4,287,054; 4,394,258; 4,431,531; 4,617,113; 4,639,313; and 4,735,709.

In a typical operation, the conditioned pulp is introduced into a vessel to form a column of aqueous pulp, and aerated water is introduced into the lower portion of the column. An overflow fraction containing floated particles of the pulp is withdrawn from the top of the body of aqueous pulp and an underflow or non-float fraction containing non-floated particles of the pulp is withdrawn from the column in the lower portion.

In several systems of this type, the aerated water is produced by first introducing a frother or surfactant into the water and passing the mixture through an inductor wherein air is aspirated into the resulting liquid. In order to obtain the required level of aeration, a high flow rate for the water must be maintained through the inductor. While recirculation systems have been devised to minimize the amount of "new" water added to the system, a significant expenditure in energy is required to move such large quantities of water.

Another problem encountered results from the difference between the concentrations of solid particles contained in slurries of different minerals. Phosphates, for example, do not typically require extensive grinding in order to liberate the desired mineral components of the pulp. As a result, the aqueous slurry or pulp fed to the flotation apparatus typically consists of approximately seventy-five percent (75%) solids and twenty-five percent (25%) water.

Sulfides, on the other hand, approach the opposite extreme, and typically require extensive beneficiation through grinding of the material to a very fine state in order to liberate the desired minerals from the gangue.

The addition of water throughout the sorting, grinding, and classifying stages of the beneficiation process results in an aqueous slurry comprising approximately ten percent (10%) solid matter and ninety percent (90%) water. Thus, the addition of significant additional amounts of water through the introduction of the aerated water is undesirable in that significant amounts of the finely ground valuable minerals may avoid capture by the aeration bubbles and remain suspended in the liquid component of the slurry.

Another method for introducing minute air bubbles into the flotation vessel comprises a sparging system such as that disclosed in U.S. patent No. 4,735,709. Spargers or microdiffusers are normally tubular members formed of porous material such as sintered stainless steel, porous plastic, ceramic or the like, with a porous wall having a typical average pore size of about 50 microns.

The sparger is placed within the flotation vessel and air under pressure is introduced into its interior. The pressurized gas or air within the interior chamber is forced through the pores and into the aqueous pulp in the flotation chamber.

While spargers are used with considerable success, they do have certain disadvantages, including the tendency of the small pores to become clogged with contaminants. Also, the spargers typically used, because they are inserted within the flotation column, do not themselves supply water to the vessel and the replacement water must be provided with another system.

The method and apparatus of the present invention, however, resolve the difficulties indicated above and afford other features and advantages heretofore not obtainable.

SUMMARY OF THE INVENTION

It is a primary object of the present invention to provide a flotation apparatus for the concentration of minerals which optimizes the separation efficiency.

Another object is to achieve the above result with a minimal amount of water inflow.

Still another object of the invention is to provide a flotation apparatus for the concentration of minerals requiring a significantly reduced energy condition, thereby providing more economic operation.

A further object of the invention is to provide a bubble generator adapted for use with a flotation column, which bubble generator is external of the flotation column and thus easily accessible for maintenance.

A still further object of the invention is to produce bubbles for a froth flotation column wherein the bubbles are finer in size than those that can be produced by conventional spargers and with a minimum amount of supply liquid.

In accordance with the present invention, minute bubbles or microbubbles are first generated in a flowing stream of aqueous liquid and then introduced into the flotation column. The system utilizes a microbubble generator having a tubular housing with an inlet end and an outlet end. Located coaxially within the housing is an inner member with an elongated exterior cylindrical surface.

A porous tubular sleeve is mounted between the housing and the inner member coaxially therewith to define with the cylindrical interior surface of the housing an elongated air chamber of annular cross section. The porous sleeve also has a cylindrical inner surface that defines, with the exterior surface of the inner member, an elongated liquid flow chamber of thin, annular cross section.

An aqueous liquid is supplied through a fitting on the housing to the liquid flow chamber and is forced through the flow chamber at a relatively high flow rate and in a thin, annular space to minimize the contact between the liquid and the inner surface of the porous sleeve. Air or other gas under pressure is supplied through another fitting on the housing to the air chamber so that air is forced radially inwardly through the porous sleeve and is diffused in the form of microbubbles in the flowing stream.

Because of the velocity of the flowing stream, the gaseous bubbles passing through the porous sleeve are sheared at the interior surface to produce very fine microbubbles. Accordingly, an aqueous liquid infused with minute gaseous bubbles is discharged from the outlet end of the housing and piped to the flotation vessel.

The resulting product is introduced into the flotation column through distribution pipes with openings of a size calculated to maintain a pressure condition that prevents coalescence of the bubbles.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of a flotation vessel for use in a froth flotation system and having a means in accordance with the present invention for introducing air in the form of minute bubbles into the aqueous slurry, with parts broken away for the purpose of illustration;

FIG. 2 is a broken, elevational view of a microbubble generator embodying the invention, as used in the air induction system shown in FIG. 1;

FIG. 3 is a fragmentary, sectional view on an enlarged scale showing the upper end or inlet end of the microbubble generator of FIG. 2;

FIG. 4 is a sectional view taken on the line 4-4 of FIG. 3;

FIG 5 is a fragmenetary, sectional view on an enlarged scale showing the lower end or outlet end of the microbubble generator of FIG. 2;

FIG. 6 is a sectional view taken on the line 6-6 of FIG. 5;

FIG. 7 is a fragmentary, elevational view of a distributor tube of the type used in connection with the method of the present invention; and

FIG. 8 is a sectional view taken on the line 8-8 of FIG. 7.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring more particularly to the drawings, and initially to FIG. 1, there is shown a fluid vessel or cylinder 10 for use in the separation of minerals in finely comminuted form from an aqueous pulp by the froth flotation process and which utilizes an improved means in accordance with the invention for introducing gas in the form of minute bubbles into the liquid flotation column. The vessel includes a feed well 11 for feeding the aqueous pulp into the upper end of the flotation column, the pulp being received through a feed tube 12 from an external source of aqueous slurry to deliver a controlled quantity of the slurry to the feed well 11. The feed well 11 may include baffles (not shown) so that the aqueous slurry fed into the feed well becomes distributed throughout the flotation column.

The introduction of aerated water into the fluid vessel 10 is accomplished by means of an air system 20. The aerated water that is introduced tends to flow upwardly through the aqueous slurry and the particulate matter suspended therein so that either the particles of the desired valuable mineral or the particles of the gangue suspended in the aqueous slurry adhere to the rising bubbles and collect at the upper end of the flotation column in the form of a froth. A launder 13 is provided at the upper end of the vessel and is adapted to receive the froth which overflows from the top of the vessel. An output conduit 14 is provided to convey the overflowing froth from the launder 13 to further processing or storage apparatus.

The solid matter not captured by the levitating gas bubbles gravitates downwardly through the aqueous slurry until it collects at the bottom of the column and is removed through an underflow duct 15.

The Air System - General Arrangement

The system for introducing an aqueous mixture containing minute gas bubbles includes an upper system 21 and a lower system 22, each of which has a pair of microbubble generators 50 formed in accordance with the invention. In the preferred arrangement, only one of the generators 50 of each pair is used at a time, the other generator being used as a spare, such as during repair and replacement. Gas under pressure is supplied to one of the lower system microbubble generators 50 through a branched air inlet 23 that communicates with a compressor 24. An aqueous liquid is supplied to each of the lower microbubble generators 50 through a branched water inlet 25 which is connected to a pump 26 to provide the desired pressure and flow rate.

The resulting aerated liquid is exhausted from the generators through a branched water outlet 27 and then conveyed through a pipe 28 to a manifold 30 located on the vessel. In the present case, the manifold has four outlet pipes 31, 32, 33, and 34 which connect to four distributor tubes 36, 37, 38, and 39, which extend through pipe housings 41, 42, 43, and 44, respectively, into the interior of the vessel. The distributor tubes are provided with a predetermined pattern of small openings through which the aerated water is discharged into the flotation column.

The upper air system 21 is essentially identical to the lower system 22 and, accordingly, like numerals are used to indicate like parts in the system components.

It has been found that the most effective arrangement comprises supplying about one-half or more of the aerated water through the lower system 22 and one-half or more through the upper system 21. Also, it is desirable that the pipe sizes be selected to retain a uniform flow cross section through the length of the flow so as to maintain a uniform velocity.

The Microbubble Generators

The four microbubble generators 50 are all identical and provide a new and improved means for aerating the aqueous liquid flowing into the flotation column, while at the same time minimizing the amount of water or aqueous liquid required to introduce an optimum volume of gas. The generators 50 are each in the form of an elongated tube, typically about 48 inches long (24 inches for some small cells), and most of the components are fabricated of stainless steel to eliminate the effects of corrosion and scale.

Each of the generators includes an upper end member 51 and a lower end member 52 separated by an elongated, cylindrical, tubular housing 53. The upper end of the tubular housing 53 seats in an annular groove 54 formed in the adjacent face of the upper end member 51 and the lower end of the tubular housing 53 seats in an annular groove 55 formed in the adjoining face of the lower end member 52. The resulting assembly is held in place by an elongated, threaded rod 56 which extends through a central bore 57 in the upper end member 51 and axially through the entire length of the tubular housing 53. The axial bore 57 has a narrowed throat portion 58. The lower or inner end of the threaded rod 56 screws into a threaded bore 59 in the lower end member 52. A cap nut 60, with an associated cap centering washer 60a, is tightened down on the upper end of the threaded rod 56 and seats in the throat portion 58 to secure the assembly.

The upper end member 51 has an air inlet port 61 that extends in an axial direction and a radial water inlet port 62. Both ports 61 and 62 are adapted to receive fittings that connect to air and water inlet lines, respectively.

The upper end member 51 has an inner fitting 63 associated therewith that seats against an annular axial extension 64 formed on the upper end member so that it does not block the air inlet port 61.

An axially extending locater pin 65 that extends into mating bores in the upper end member 51 and in the inner fitting 63 prevents relative rotation between the two parts.

An axially extending neck portion 66 of the inner fitting 63 extends upwardly into the axial bore 57. The lower portion of the neck 66 has a pair of spaced, annular grooves 67 and 68 which receive seal rings 69 and 70.

A central axial bore 71 is formed in the inner fitting 63, the bore being provided with a lower tapered portion 72. A tangential slot 73 is milled in the neck portion 66 adjacent the radial water inlet port 62 to provide a passage for water through the neck portion and into the central bore 71. The locater pin 65 assures that the tangential slot is correctly aligned so that the water passage is not blocked.

The lower end of the lower end member 52 has an axial threaded outlet bore 75 formed therein that receives a fitting for the outlet line 27 for the aerated aqueous liquid. The outlet bore 27 communicates with a tapered passage 76, which in turn communicates with a plurality of axially extending, parallel ports 77 formed in a circular pattern in the lower end member 52.

Located within the tubular housing 53 and coaxial therewith is a porous, tubular sleeve 80 that extends axially between the lower end member 52 and the inner fitting 63. The upper end of the sleeve 80 seats in an annular groove 81 formed in the inner fitting 63 and bears against an annular gasket 83 positioned in the groove 81. The lower end of the porous sleeve seats in an annular groove 82 formed in the lower end member 52 and bears against an annular gasket 84 that is seated in the bottom of the groove 82.

In the present instance, the porous sleeve 80 is formed of a porous plastic material manufactured by Porex Technologies, of Fairburn, Georgia. The material is a porous polypropylene and has a typical pore size of about 75 microns. The designation used by the manufacturer is POREX XM-1339. Other materials may be used, however, such as sintered stainless steel, porous ceramics, etc. The sleeve 80 is 2.925 inches O.D., and has a wall thickness of about .375 inch.

The exterior surface of the porous sleeve 80 and the interior surface of the tubular housing 53 define an elongated, annular air chamber 85 that communicates with the air inlet port 61. The lower end member 52 has a drain port 87 formed therein communicating with the air chamber 85 and an associated drain valve 88 to drain off accumulated oil and particles when necessary.

Located within the porous sleeve 80 is an axially extending filler tube 90 that extends between an upper tip member 91 and a lower tip member 95. The tip members 91 and 95 both have a frustoconical shape, the upper member 91 tapering in an upward direction and the lower tip member 95 tapering in a downward direction to encourage laminar flow.

The upper tip member 91 has an annular rabbet 92 formed in its base that receives the upper end of the filler tube 90 and also has a central axial bore 93 with a threaded upper end portion 94 adapted to be threadedly received on the threaded rod 56.

The lower tip member 95 has an annular rabbet 96 formed in its base portion and adapted to receive the lower end of the filler tube 90. The lower tip member also has a central axial bore 97 with a threaded portion 98 at its lower end adapted to be threaded onto the threaded rod 56. The exterior surface of the filler tube 90, together with the tapered exterior surfaces of the two tip members 91 and 95, define with the interior surface of the porous sleeve 80, a thin, annular fluid passage 99 for the aqueous fluid that is supplied through the inlet port 62. It is desirable that the fluid passage 99 be relatively thin in its cross section perpendicular to the direction of flow and in the embodiment shown, the passage is about .094 inch in radial thickness.

The aqueous liquid entering through the port 62 passes through the slot 73 into the central bore 71 within the inner fitting 63. The flow proceeds downwardly through the lower tapered portion 72 adjacent the central bore 71 and then outward into the annular flow passage 99, as shown in FIG. 3. As the water flows along the annular passage 99, gas passing through the porous sleeve 80 becomes entrained in the flow so that the resulting aqueous fluid that exits through the outlet 75 has a volume of gas entrained therein in the form of minute bubbles.

Because a relatively high velocity or flow rate of water or aqueous liquid is maintained through the passage 99, gas bubbles that emerge at the interior surface of the porous sleeve are effectively sheared by the flow to obtain extremely small bubble sizes.

Because the radial thickness of the water flow passage 99 is relatively small, e.g., .094 inch, the surface area of the flowing mass of water that contacts the interior surface of the porous sleeve 80 is relatively large with respect to the cross-sectional area of the flow passage. This assures that a maximum amount of gas is entrained in the flowing liquid in the form of minute bubbles.

As indicated above, it is important that a constant pressure be maintained in the air systems between the microbubble generators 50 and the distributor tubes 36, 37, 38, and 39 in order to prevent bubble expansion or growth prior to their delivery to the flotation column. If pressure and flow velocity are not properly maintained, the minute bubbles may coalesce and be less effective in separating the desired float fraction from the aqueous pulp.

In order to maintain this pressure, the small ports or holes 100 formed in the distributor tubes must be of a proper size to assure that a substantial pressure drop does not occur within the distributor tubes. A preferable arrangement is to provide openings located on the bottom of the tube and spaced between about 2.5 to 7.5 inches apart. The openings preferably have a diameter of between about one-sixteenth inch and one-eighth inch. These spacings and hole sizes may vary, of course, depending upon the size of the vessel and the length of the particular distributor tube.

For larger vessels, the tubes may extend into the flotation column from opposite sides of the vessel from separate manifolds. Preferably, tube lengths are kept substantially equal. Some typical hole sizes and spacings are shown in Table I below, together with dimensions for respective microbubble generators 50.

TABLE I

	Microbubble Generator 50				Distributor Tubes (.5 inch O.D.)			
Cell Dia. (ft.)	Housing 53 (Inches) O.D. /I.D.	Porous Tube 80 (Inches) O.D. / I.D.	Inner Tube 90 (Inches) O.D.	Passage 99 Area (Sq.Inch)	Hole Dia. (Inch)	Number of Holes/Tube Upper/Lower	Area Per Hole (Sq.Inch) Upper/Lower	Total Area of Holes (Sq.Inch)
2	4 /3.75	2.925 /2.215	2.0	.712	1/16	12/16	.037/.049	.086
2.5	4 /3.75	2.925 /2.215	2.0	.712	5/64	12/16	.057/.076	.133
3	4 /3.75	2.925 /2.215	2.0	.712	3/32	12/16	.083/.110	.193
5.5	4 /3.75	2.925 /2.215	1.66	1.69	7/64	28/40	.263/.370	.376
6.5	4 /3.75	2.925 /2.215	1.66	1.69	1/8	30/42	.368/.520	*
8.0	4 /3.75	2.925 /2.215	1.315	2.50	1/8	46/62	.565/.760	*

* Individual generators supply mixture to each level for these cells.

Operation

The operation of the system shown will be described with respect to a vessel 10 filled with a particular aqueous pulp containing a mixture of a valuable mineral and gangue and wherein it is desired to separate by froth flotation the valuable mineral in the froth at the top of the column. The froth containing the float fraction is removed through the launder 13.

During the process, the aqueous pulp will be fed at a controlled rate through the feed pipe 12 into the feed well 11. Aerated water will be fed at a controlled rate through both the upper and lower distribution systems 21 and 22, the flow rate being about twice as great in the lower system as in the upper or intermediate system.

The process begins with the infusion of an aqueous liquid with microbubbles by means of the microbubble generators 50. Gas is supplied to the generators by the compressor 24 and water is supplied by means of the water pump 26 or head pressure, which pumps the water at a desired predetermined pressure. Recommended flow rates for various sizes of flotation cells are shown in tabular form in Table II below, it being understood that these are variable. For example, satisfactory operation has been achieved using less water and air at lower pressure, ranging as low as 40 psi.

TABLE II

CELL DIA.	GENERATOR PSI (AIR)	AIR SUPPLY SCFM	GENERATOR PSI (WATER)	WATER SUPPLY GPM
8"	70	2	70	.05
2.0'	70	15	70	4
2.5'	70	20	70	5
3.0'	70	30	70	8
5.5'	70	100	70	25
6.5'	70	140	70	35
8.0'	70	200	70	50
10.0'	70	320	70	80
12.0'	70	450	70	115

The gas enters each of the microbubble generators 50 through the inlet port 61 and fills the annular space 85 surrounding the exterior surface of the porous sleeve 80. The aqueous liquid, which is preferably water mixed with a typical surfactant of the type well known in the art, is supplied through the radial port 62 and flows through the central passage 71 into the annular water flow passage 99, where it flows along the interior surface of the porous sleeve 80.

The gas pressure in the gas chamber 85 forces air through the small pores (i.e., about 75 microns in pore size), so that it emerges at the cylindrical interior surface of the sleeve, where it contacts the flowing aqueous liquid. Due to the relatively high velocity of the liquid flow, the bubbles are sheared from the surface as they emerge and become entrained in the form of minute bubbles in the flowing stream.

By the time the flowing stream has reached the lower end of the microbubble generator, an optimum volume of gas has been entrained in the stream in the form of minute bubbles and the resulting mixture exits through the outlet 75. The stream is then conveyed through the line 27 to the respective manifold 30. There it divides into four flow paths through the pipes 31, 32, 33, and 34, and ultimately into the distributor tubes 36, 37, 38, and 39.

The resulting liquid is then introduced into the flotation column through the small holes 100 in the respective tubes. The minute gas bubbles then levitate through the aqueous slurry in the flotation column and the particles of the desired valuable mineral adhere to the bubbles and collect at the upper end of the flotation vessel in the form of froth. The froth overflows into the launder 13, where it is collected and delivered to the output conduit 14, which conveys it away for further processing.

Using the well-understood principle that bubble-rise time diminishes with size diminution, the apparatus herein disclosed provides for greater efficiency in material recovery. Since bubble size is small, retention time within the water column is correspondingly large. The finer bubbles provide maximum surface area for attachment to descending particles. Turbulence within the water column is minimized whereby bubbles tend to follow only substantially vertical paths. Larger bubbles tend to be erratic and to create voids therebelow which result in descending particles moving somewhat laterally rather than downwardly.

The distributor pipes 36, 37, 38, 39 extend horizontally across the cross section of the cell (as shown in FIG. 1), have evenly spaced openings 100, and are evenly spaced apart so as to provide a substantially uniform cross section of bubbles thereabove in the column 10.

Two levels or elevations of distributor pipes are used, thereby creating two recovery zones within the column 10, one between the two pipe sets and the other above the upper set. The lower set is two to four feet above the tailings discharge port (not shown) in the bottom of the column 10, while the upper set is disposed midway between the lower set and the upper end of the column 10.

In the upper recovery zone, bubbles from both pipe sets will obtain. In the lower zone, the only bubbles will be those from the lower set. Thus, bubble density is correspondingly different in the two zones. Bubbles in the upper zone, being more concentrated, attach to and immediately float off that particle fraction most susceptible to float separation. The remaining particles descend through the lower zone where the fine bubbles are ascending relatively slowly, the slow ascent creating more time during which attachment to descending particles may occur. Primary recovery, therefore, may be said to occur in the upper zone, and scavenging in the lower zone.

Of importance is the fact that bubble generation and sizing are external to column 10 and that the same size bubbles are fed to both of the upper and lower sets of pipes. Since rising bubbles progressively expand in size, those bubbles introduced at the lower level will enlarge by the time they reach the upper level. Thus, some of the desired qualities of tiny bubbles will there be lost. However, tiny bubbles are introduced at the upper level and will rise vertically, providing maximum surface area for particle attachment. Thus, by means of multilevel bubble introduction of externally generated bubbles, bubble size is maintained optimally small, thereby enhancing the probability of particle attachment.

Tiny bubble introduction at the different levels also minimizes turbulence within the column water. Smaller bubbles tend to create less disturbance and to follow vertical paths. Thus, there will be minimal turbulence in the lower zone, as bubble size is small. In the upper zone where bubble concentration is greater, the distance to the water surface is relatively short and the introduction of small bubbles tends to infiltrate smaller bubbles with the enlarged ones and ascendancy remains substantially vertical. Turbulence in the form of circular motion or boiling action is thereby minimized, contributing further to the efficiency of material pick-up. The two sets of distributor pipes at the two levels, receiving and emitting the same size bubbles, inhibit development of turbulence, thereby enhancing column efficiency.

While air and water are preferred in the working embodiments of this invention, gases other than air, such as nitrogen, and liquids other than water may be used. Thus, the words "air" and "water" and the term "aerated water" are intended to include these equivalents.

In the present invention, generation of micro-sized bubbles enhances the efficiency of the flotation mechanism through increased surface area of the bubbles while reducing the air volume requirements typical of present flotation mechanisms. The system requires lower air and water pressures (40-70 psi) and lower water volume (0.5 GPM/CFM) than other microbubble sparger systems, which require minimum 80 psi air and water pressure and water requirements of 1 - 1.5 GPM/CFM.

While the invention has been shown and described with respect to a specific embodiment thereof, this is intended for the purpose of illustration rather than limitation, and other variations and modifications of the specific method and apparatus herein shown and described will be apparent to those skilled in the art, all within the intended spirit and scope of the invention. Accordingly, the patent is not to be limited in scope and effect to the specific embodiment herein shown and described, nor in any other way that is inconsistent with the extent to which progress in the art has been advanced by the invention.

Claims

1. Apparatus for generating gaseous bubbles in a flowing liquid stream for use in a froth flotation system, comprising:
a tubular housing with an inlet end and an outlet end and having an elongated interior surface;
a coaxial inner member located within said housing and having an elongated exterior surface;
a porous tubular sleeve mounted between said housing and said inner member and coaxial therewith, said sleeve having an outer surface that defines with said interior surface of said housing, an elongated gas

chamber of annular cross section, and an inner surface that defines with said exterior surface of said inner member, an elongated liquid flow chamber of annular cross section;
means operatively associated with said housing for supplying an aqueous liquid to said liquid flow chamber and for flowing said liquid through said liquid chamber in an axial direction from said inlet end to said outlet end;
means operatively associated with said housing for supplying air under pressure to said air chamber whereby air is forced radially inwardly through said porous sleeve and is diffused in the form of microbubbles in said flowing stream so that an aqueous liquid infused with air is discharged from said outlet end of said housing.

2. Apparatus as defined in claim 1, wherein said porous sleeve is formed of porous polypropylene plastic.

3. Apparatus as defined in claim 1, wherein said porous sleeve has pores formed therein with an average pore size of about 5-100 microns.

4. Apparatus as defined in claim 1, wherein said porous sleeve has a tubular cylindrical form.

5. Apparatus as defined in claim 4, wherein said porous sleeve has a wall thickness of about .2 to .4 inch.

6. Apparatus as defined in claim 4, wherein said flow passage has a tubular cylindrical cross section.

7. Apparatus as defined in claim 6, wherein the radial thickness of said flow passage is no greater than about 0.3 inch.

8. Apparatus as defined in claim 1, wherein the gas pressure maintained in said gas chamber is about 40-70 psi.

9. Apparatus as defined in claim 8, wherein the supply pressure used to move said aqueous liquid through said flow passage is about 40-70 psi.

10. A method for generating microbubbles in a flowing stream for use in a froth flotation system, comprising:
introducing air under pressure into a closed chamber defined in part by the exterior surface of a porous tubular sleeve;
pumping a stream of aqueous liquid through a flow passage defined in part by the interior surface of said porous sleeve and in part by an elongated inner member located within said porous sleeve and having an outer surface coextensive with and uniformly closely spaced from said interior surface of said sleeve so that said passage is relatively thin as viewed in section perpendicular to the direction of flow;
whereby gas is forced radially inwardly through said porous sleeve and is diffused in the form of microbubbles in said flowing stream.

11. A method as defined in claim 10, wherein said porous sleeve is formed of porous polypropylene plastic.

12. A method as defined in claim 10, wherein said porous sleeve has pores formed therein with an average pore size of about 5-100 microns.

13. A method as defined in claim 10, wherein said porous sleeve has a tubular cylindrical form.

14. A method as defined in claim 13, wherein said porous sleeve has a wall thickness of about .2 to .04 inch.

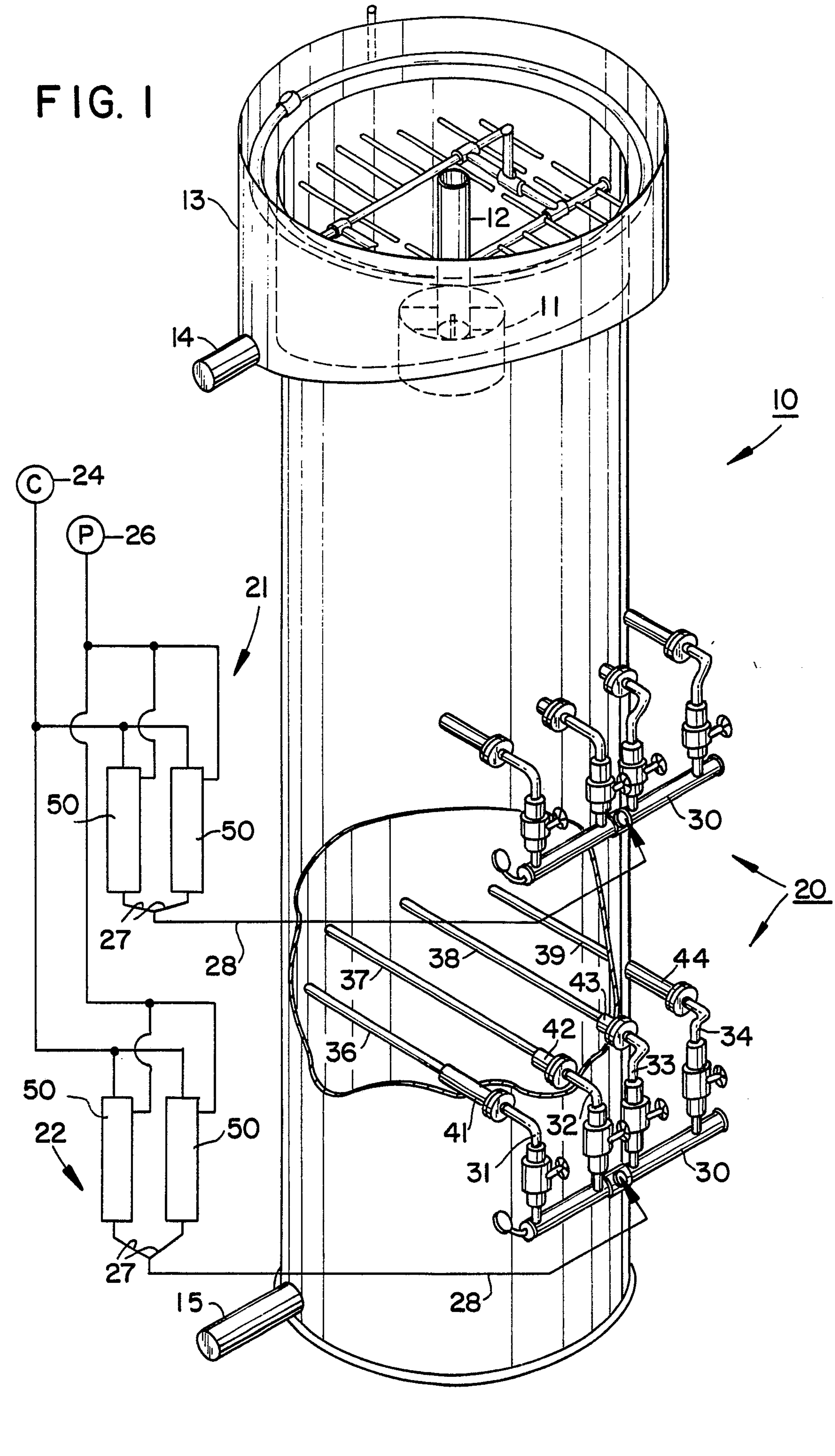
15. A method as defined in claim 13, wherein said flow passage has a tubular cylindrical cross section.

16. A method as defined in claim 15, wherein the radial thickness of said flow passage is no greater than about .1 to .3 inch.

17. A method as defined in claim 10, wherein the gas pressure maintained in said closed chamber is about 40-70 psi.

18. A method as defined in claim 17, wherein the supply pressure used to pump said aqueous liquid through said flow passage is about 40-70 psi.

FIG. I



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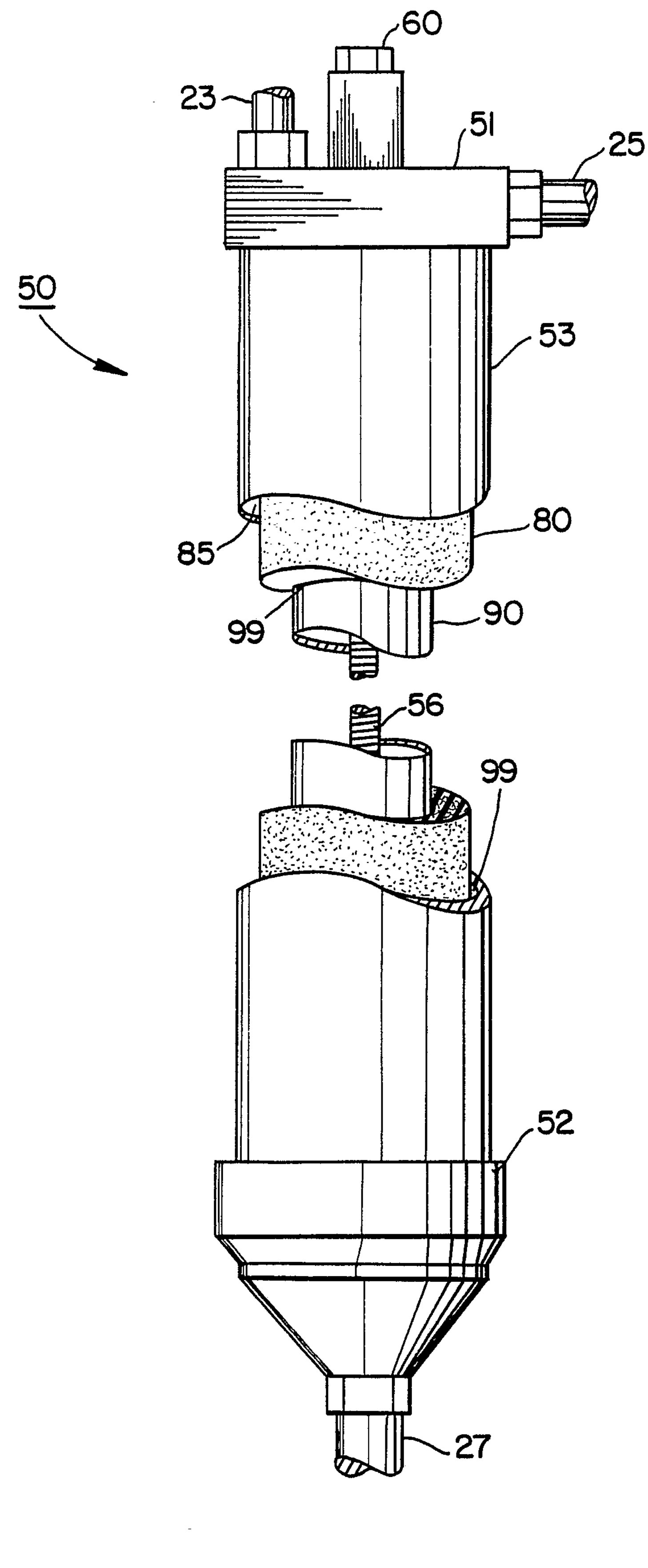


FIG. 2

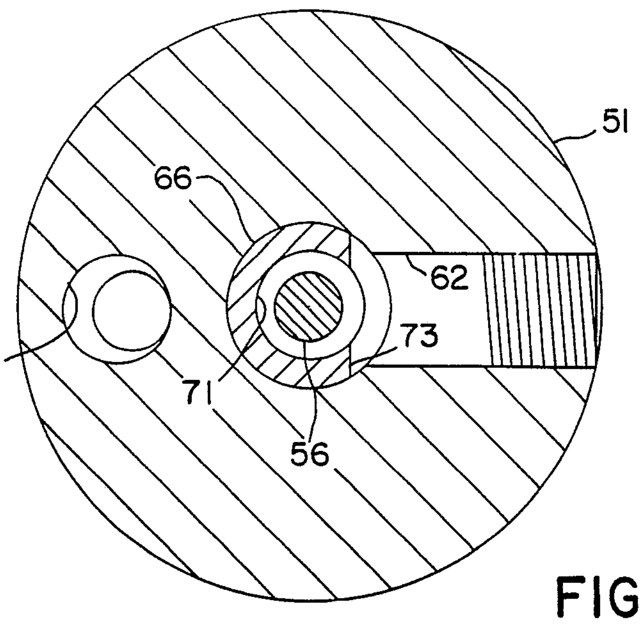
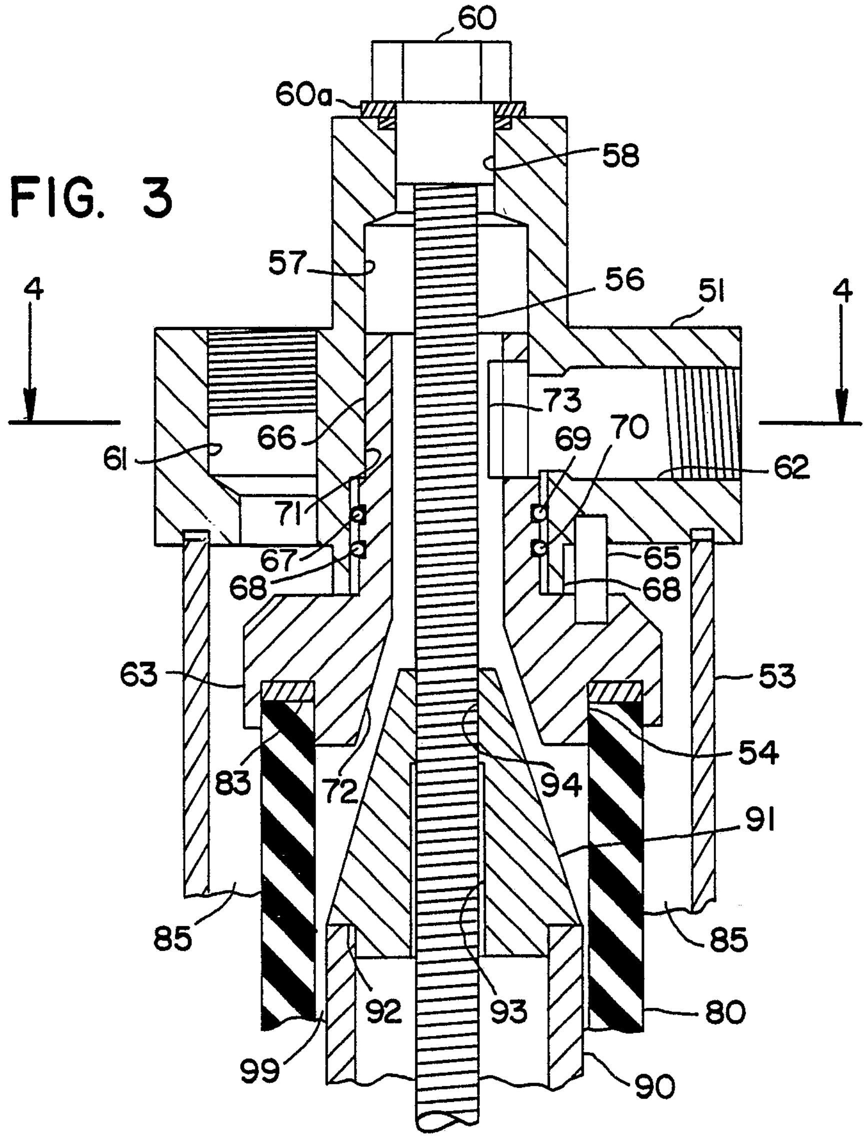

51
66
62
73
61
71
56

FIG. 4

FIG. 3


60
60a
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4
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93
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99
90

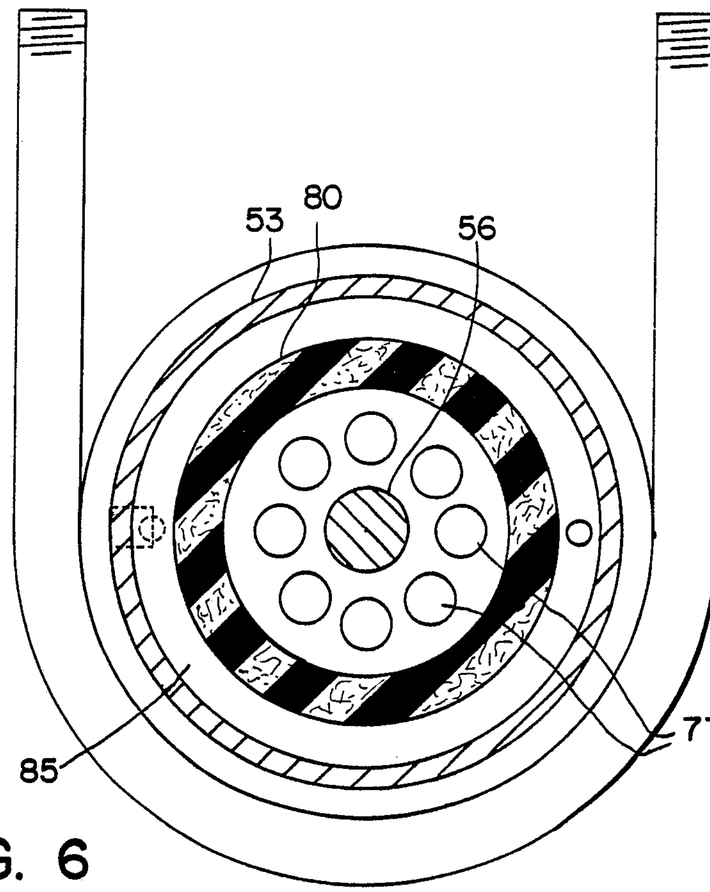
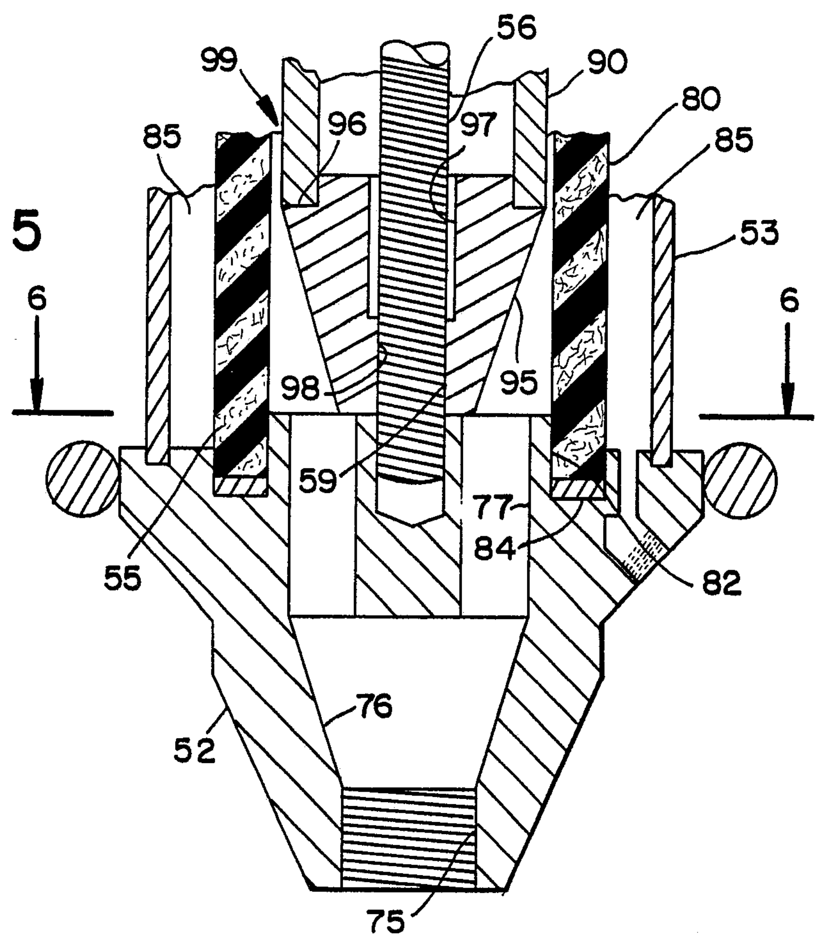

53
80
56
77
85

FIG. 6

FIG. 5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75

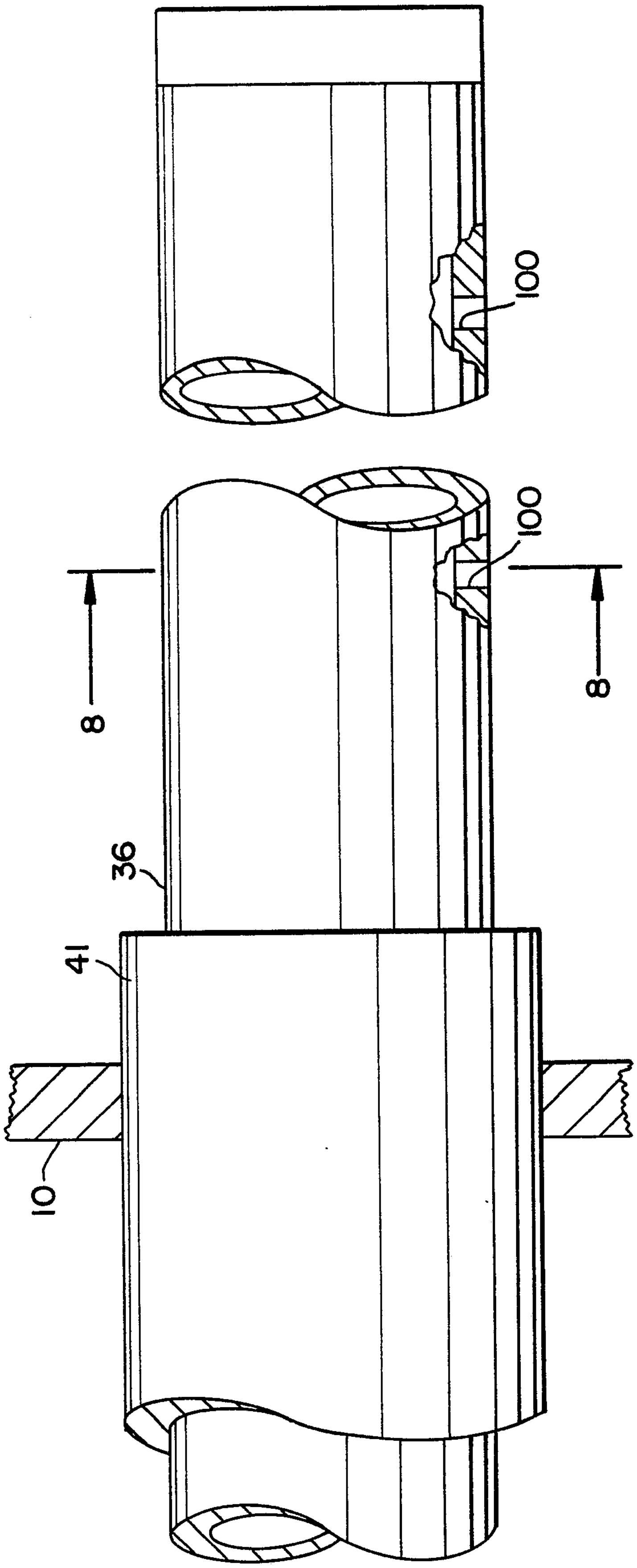

FIG. 7

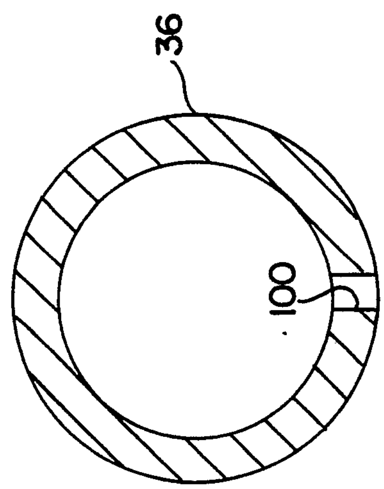

FIG. 8