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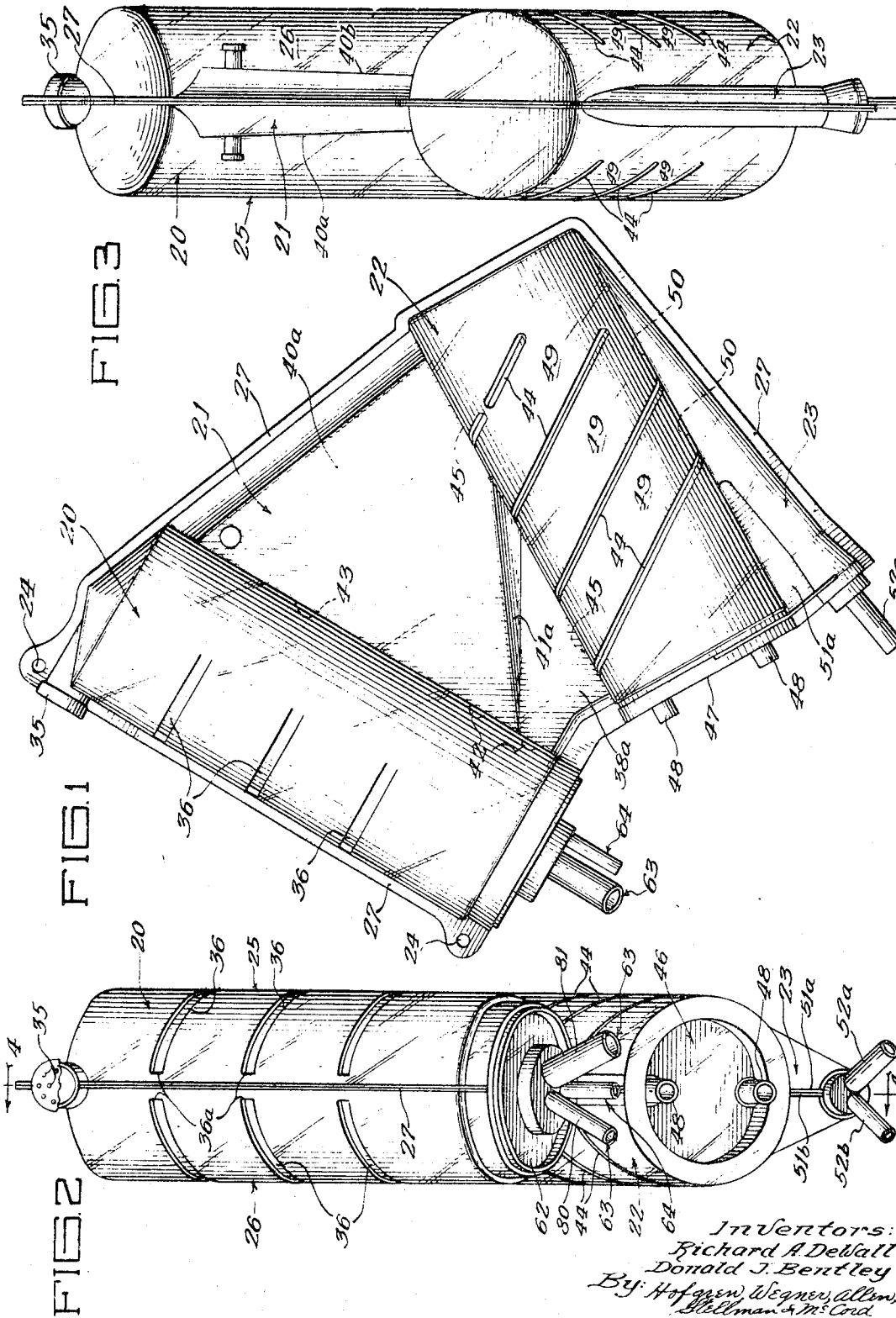
D. J. BENTLEY ET AL

3,488,158

BUBBLER ASSEMBLY FOR OXYGENATOR

Filed Dec. 12, 1966

5 Sheets-Sheet 1



Inventors:
Richard A. DeWall
Donald J. Bentley
By: Hofgren, Wegner, Allen,
Stellman & McCord
Attorneys

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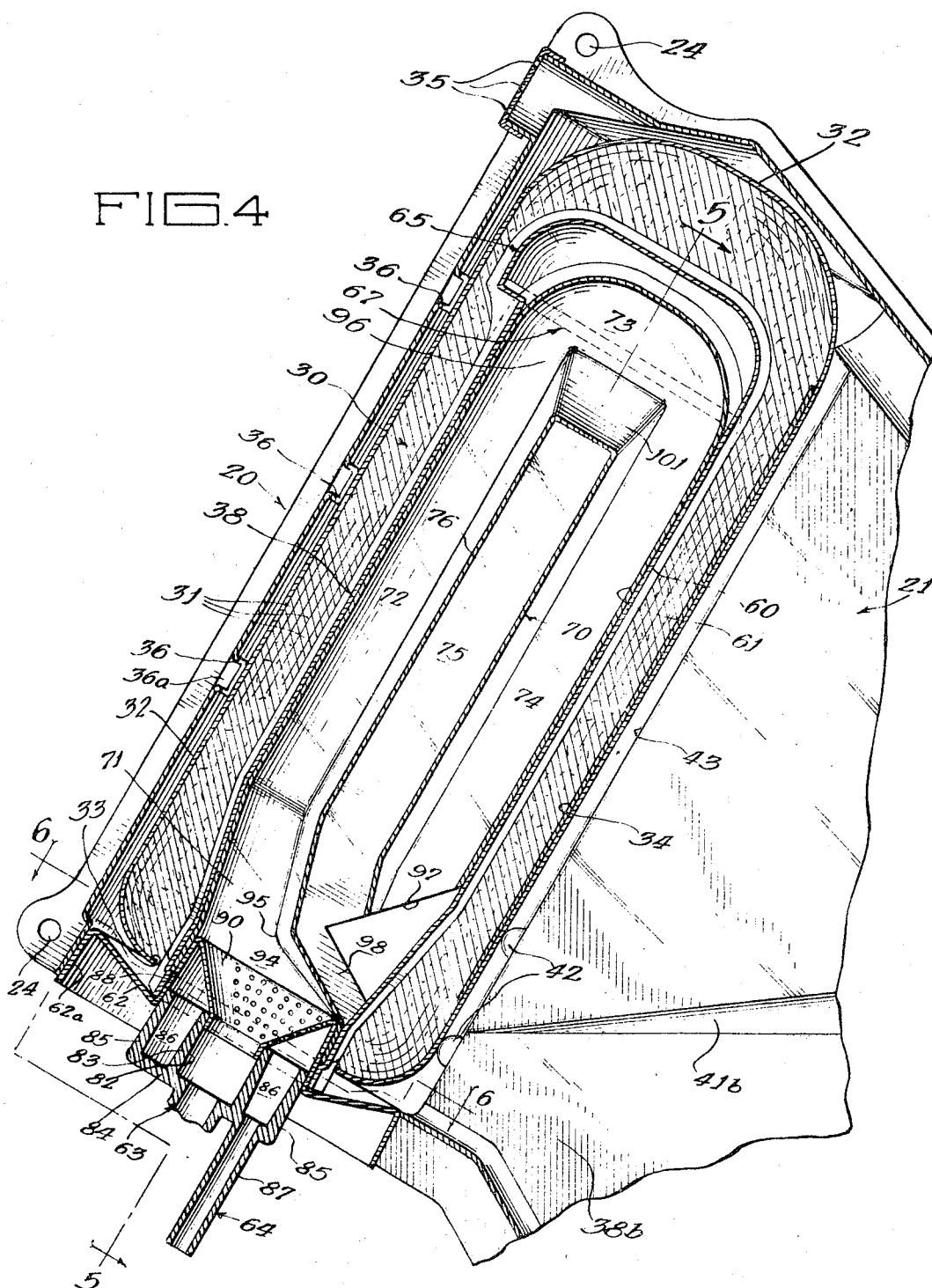
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BUBBLER ASSEMBLY FOR OXYGENATOR

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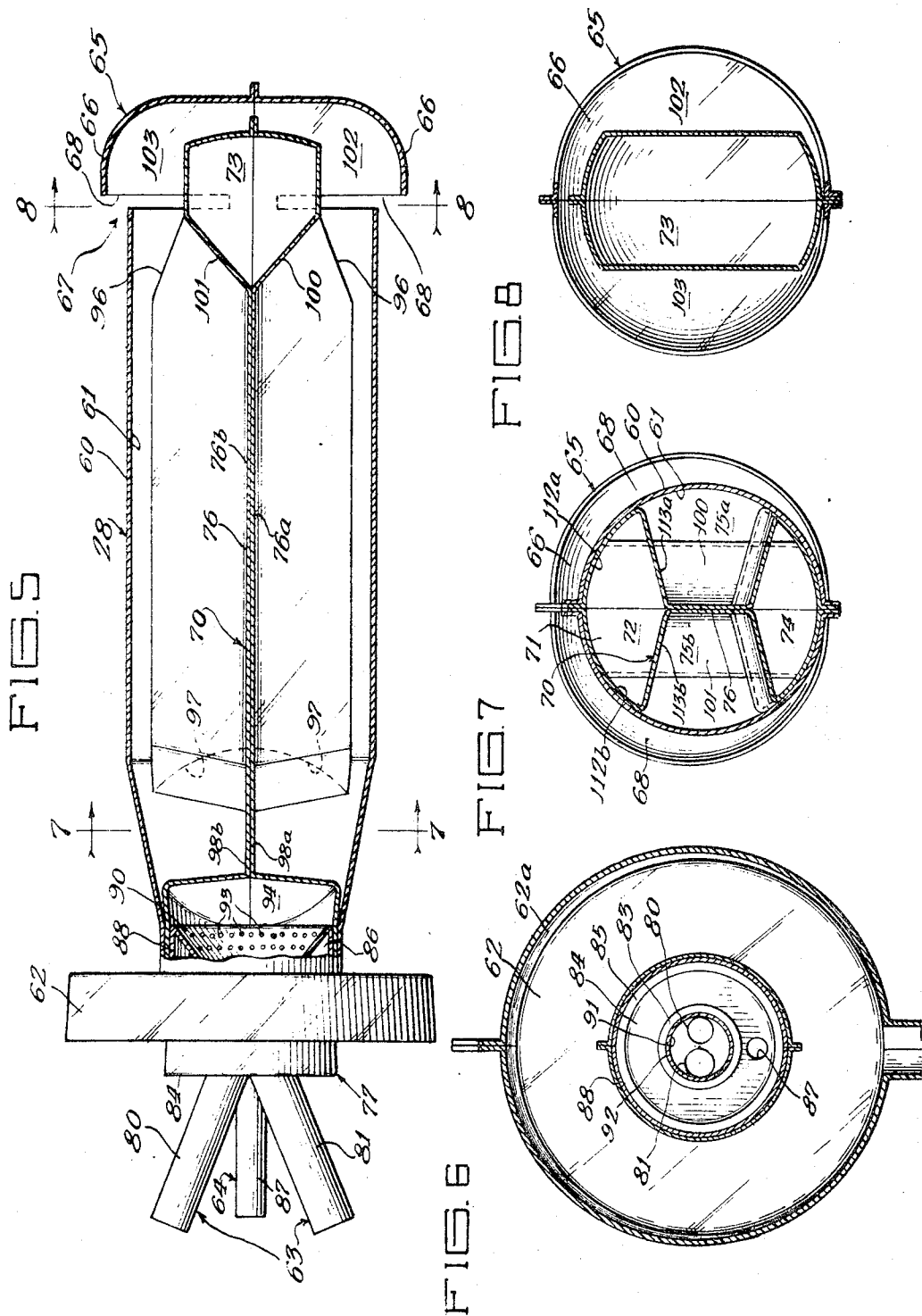
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BUBBLER ASSEMBLY FOR OXYGENATOR

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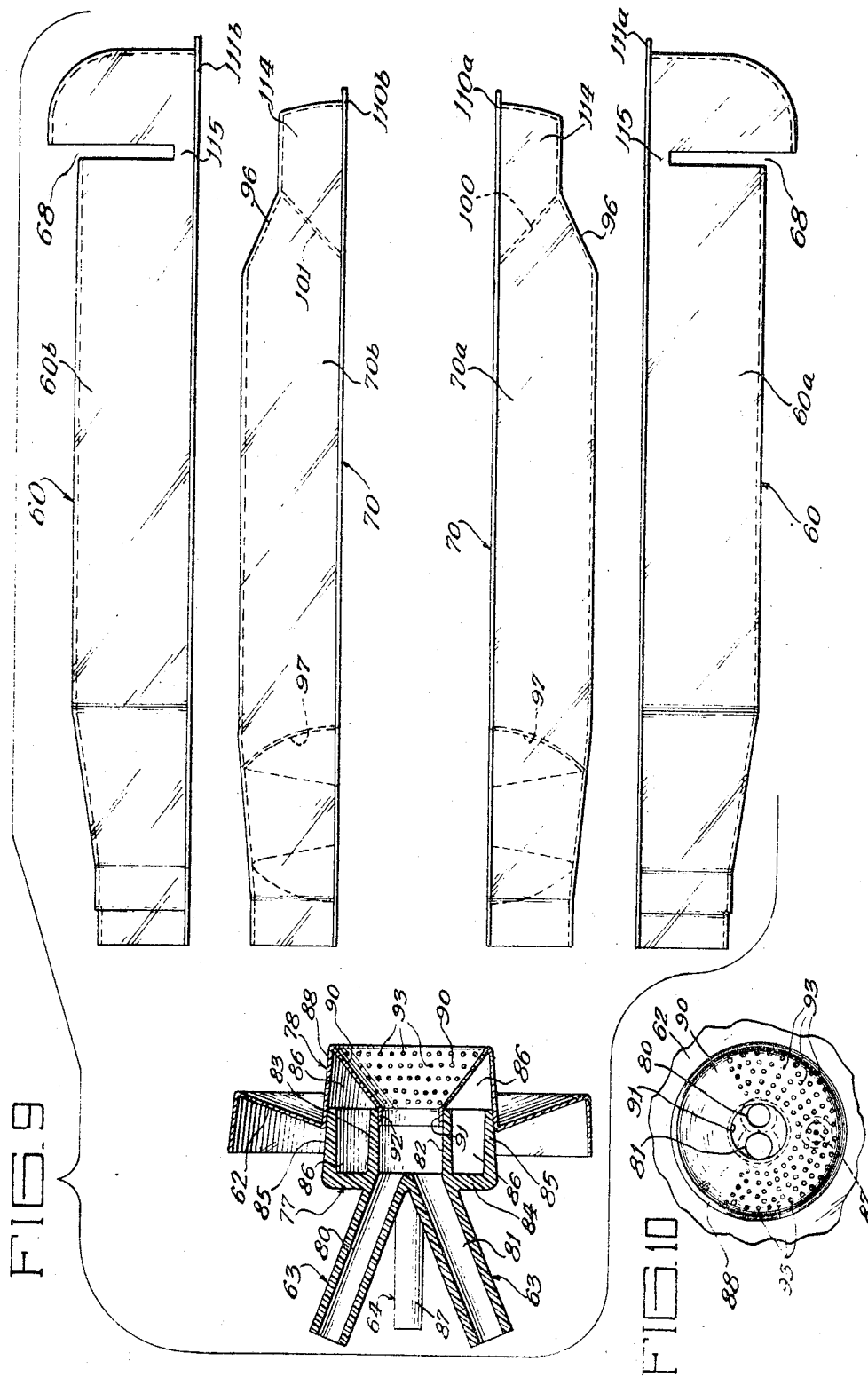
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BUBBLER ASSEMBLY FOR OXYGENATOR

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BUBBLER ASSEMBLY FOR OXYGENATOR

Filed Dec. 12, 1966

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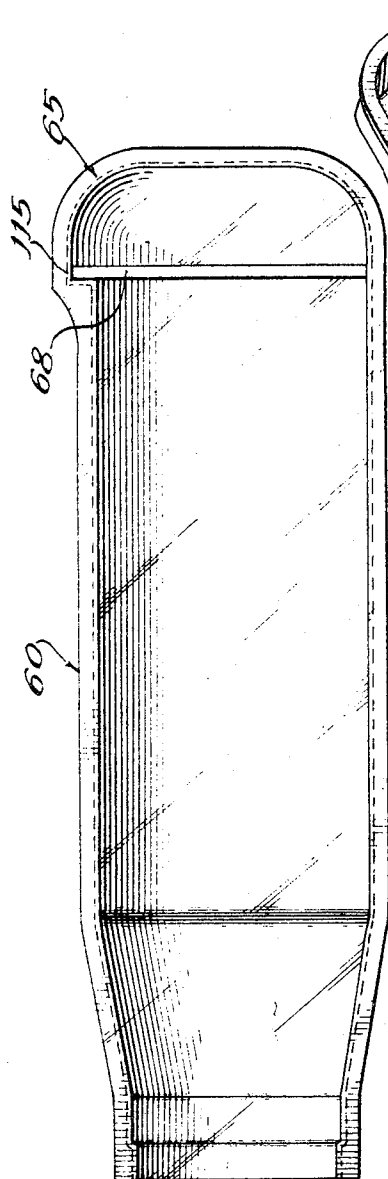


FIG. 11

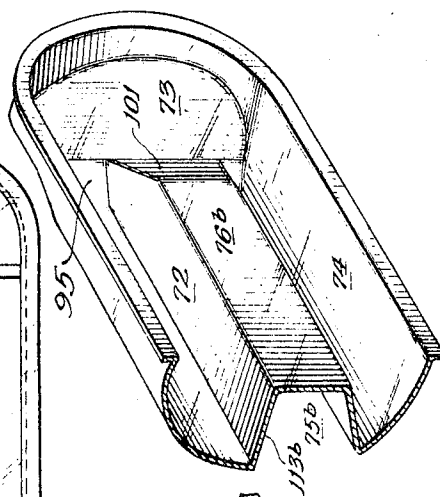
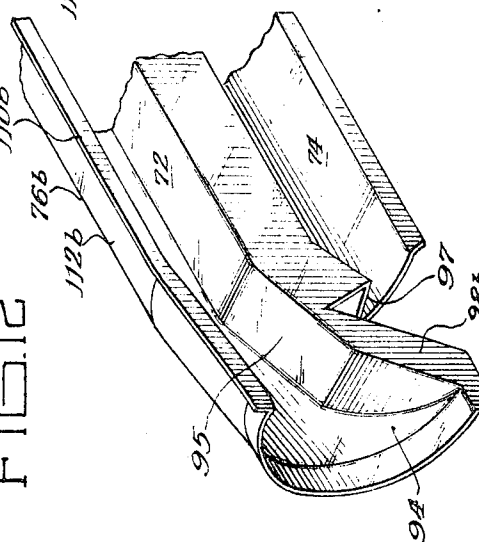


FIG. 12



1

2

3,488,158

BUBBLER ASSEMBLY FOR OXYGENATOR
Donald J. Bentley, Santa Ana, Calif., and Richard A. De Wall, Dayton, Ohio, assignors to Bentley Laboratories, a corporation of California

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U.S. Cl. 23—258.5

20 Claims

ABSTRACT OF THE DISCLOSURE

A blood oxygenator device including a bubbler assembly which comprises a hollow elongated housing having blood and oxygen inlet means at one end thereof and outlet means for blood bubbles at the opposite end thereof. The housing includes a partition means for dividing the internal chamber thereof to define a continuous closed passageway. The blood and oxygen inlet means are situated relative to one another so as to create a thin film of blood over the oxygen inlet means to cause immediate bubbling of the blood film.

This invention relates to a bubble-type oxygenator of the kind used in thoracic surgery, and more particularly to an improved bubbler assembly for effecting the transfer of oxygen to, and the release of carbon dioxide from, venous blood during such surgery.

In the present device the venous blood is caused to diverge at the inlet port into a widened shallow stream, which stream flows over a multiplicity of small apertures from which oxygen is emitted in jetting fashion to convert substantially all of the in-flowing blood into blood bubbles. The bubbled blood is then directed along a predetermined and circuitous passageway through the housing of the bubbler assembly so that the films of blood are exposed to an oxygen atmosphere over a considerable period of time. The initial portion of the passageway is positioned at an upwardly inclined angle so that unbubbled blood, which may be either carried up the passageway by the blood bubbles or be formed by the bursting of the blood bubbles, can be returned to the jetting streams of oxygen for rebubbling. The blood outlet means is located at the far or distal end of the housing from the blood inlet means, and an umbrella-like covering member is provided immediately adjacent the outlet means to direct the blood bubbles outwardly and downwardly of the housing through a defoaming mesh material which converts the blood bubbles into liquid drops and rivulets. Thus the covering member and the location of the blood outlet means prevent oxygenated blood from falling back into the bubbler assembly and thereby decrease its efficiency in operation.

RELATED APPLICATIONS

The present invention is an improvement upon the bubbler assemblies which are shown in Richard A. De Wall Patent No. 3,256,883, filed Aug. 8, 1963, issued June 21, 1966, and the patent application of Richard A. DeWall et al., Ser. No. 465,451, filed June 21, 1965, which is now pending.

SUMMARY OF INVENTION

The primary object of the present invention is to provide an improved bubbler assembly for an oxygenator for enhancing the speed and completeness of oxygen transfer to venous blood.

Another object is to provide an improved structure for intermixing inflowing blood with oxygen so that substan-

tially all of the inflowing blood is converted into bubble form within the bubbler assembly.

A further object is to provide a housing for the bubbler assembly, which housing contains a closed passageway for bubble flow of a length substantially greater than the distance between the blood inlet and outlet means of the housing.

Yet another object is to provide a divergent mouth for a blood inlet port so as to cause inflowing blood to diverge into a widened shallow stream, the mouth being provided with a multitude of small apertures emitting jets of oxygen into the stream of blood to form substantially all of the blood into blood bubbles.

A further object of the invention is to provide a covering member adjacent the blood bubble outlet port to direct the blood bubbles outwardly of the bubbler assembly and to prevent debubbled or defoamed blood from falling back into the bubbler assembly.

Another object of the invention is to provide a bubbler assembly which can be assembled from parts formed of plastic material, which is inexpensive to manufacture, which is durable in construction, and which can be pre-sterilized for use in a disposable oxygenator.

The invention is illustrated in a preferred embodiment in the accompanying drawings in which:

FIGURE 1 is a side elevational view of an oxygenator device of the type in which the instant invention is used, the view showing the oxygenator device tilted at a slightly greater angle toward the vertical than is the case when it is in ordinary use;

FIGURE 2 is an end elevational view taken from the left of FIGURE 1;

FIGURE 3 is an end elevational view taken from the right of FIGURE 1;

FIGURE 4 is an enlarged fragmentary sectional view of the oxygenating chamber and the enclosed bubbler assembly taken as indicated along line 4—4 of FIGURE 2;

FIGURE 5 is a partial sectional view of the bubbler assembly taken generally along line 5—5 of FIGURE 4, the view being confined to the bubbler assembly and its interior structure;

FIGURE 6 is a sectional view taken as indicated on line 6—6 of FIGURE 4 to show the general structural arrangement of the inlet portion of the bubbler assembly;

FIGURE 7 is a sectional view taken as indicated on line 7—7 of FIGURE 5 to show the passageways for blood bubbles within the housing of the bubbler assembly;

FIGURE 8 is a sectional view taken as indicated on line 8—8 of FIGURE 5 showing the umbrella-shaped covering member and the connecting segment joining the upper and lower segments of the passageway for blood bubbles in the housing of the bubbler assembly;

FIGURE 9 is an exploded view of the various parts which make up the bubbler assembly including a top plan view of the two outer shells which when secured together make up the housing and its covering member, a top plan view of the two inner shells or partition means which when secured together within the housing, partition the internal chamber into a circuitous passageway, and a sectional view of the inlet portions of the bubbler assembly;

FIGURE 10 is a fragmentary view of the inlet portions of FIGURE 9 as viewed from the right of the inlet portions of FIGURE 9;

FIGURE 11 is a view in side elevation of the outer shell in the upper drawing of FIGURE 9; and

FIGURE 12 is a perspective view of one of the inner shells of the partition means, a portion of the shell being in section and broken away to better show the configuration.

GENERAL ENVIRONMENT OF INVENTION

FIGURES 1, 2 and 3 each shows a bubble-type oxygenator device with which the instant invention is preferably employed. The oxygenator device shown includes an upper cylindrical chamber 20 (commonly called an oxygenating chamber), a narrow central chamber 21 and a lower cylindrical chamber 22 (commonly called a heat exchanging chamber), and a collecting chamber 23. In use, the oxygenator device may be suspended by hooks or other appropriate means passing through apertures 24 formed at opposite ends of the upper chamber 20. When in normal operation, the angle formed by the axis of the upper cylindrical chamber 20 with the horizontal is preferably in the range of approximately 35° to 50°. The structure shown in FIGURE 1 is at a slightly greater angle and is not intended to illustrate the preferred angular relationship.

The chambers 20, 21, 22 and 23 are preferably formed from a polycarbonate plastic (sold by General Electric under the trademark "Lexan") which may either be vacuum formed or injection molded to shape two self-sustaining substantially rigid shells 25, 26, which are substantially identical with each other except one is the mirror image of the other. The two shells are each provided with a coplanar peripheral flange 27, and the peripheral flanges of the two shells are adhered together by a suitable adhesive to form a unitary, transparent structure. The plastic is inert, nontoxic, impervious to the passage of gases and liquids, and sterilizable. It contains no leachable plasticizers which may be traumatic to the blood, and it is exceptionally strong and durable to withstand accidental blows or shocks. In addition, it has a natural electrical surface charge which is similar in nature to the natural charge of the hemoglobin of the blood so that there is no tendency toward adherence between the blood and the surface of the plastic.

The structure associated with the upper or oxygenating chamber 20 is best shown in FIGURE 4. This structure includes the bubbler assembly generally designated 28 of the instant invention, which bubbler assembly is preferably mounted so that its longitudinal axis substantially coincides with the longitudinal axis of the cylindrical chamber 20. The function generally of the bubbler assembly is to intermix oxygen gas with incoming venous blood so as to form films of blood in bubble form, which blood bubbles are advanced in an oxygen atmosphere through the bubbler assembly to an outlet or outlets. In other words, in the bubbler assembly oxygen is taken on by the venous blood and carbon dioxide carried by such blood is released. The degree to which the blood is saturated with oxygen at ambient temperatures and pressures depends primarily upon the extent to which all of the blood is bubbled, the character of the films in the bubbles produced (that is their thickness or thinness and size), and the time of exposure of the blood films to the oxygen atmosphere.

As the blood bubbles pass out of the outlet of the bubbler assembly, the bubbles come into contact with a defoaming means 30. The defoaming means 30 is preferably formed in the shape of a sleeve which is closed at one end and fits over the outer lateral surface of the bubbler assembly 28. The sleeve is constructed of a plurality of similarly shaped sleeve layers of knitted mesh material which layers are nested one within another to provide a multitude of tortuous paths of flow. The knitted layers 31 are preferably formed of polypropylene fibers each of which is generally smooth and round and presents no rough surfaces to the flow of blood passing there-through. Thus the layers have no rough edges which may cause damage to the hemoglobin. The polypropylene layers are impregnated or coated with a nontoxic anti-foam composition of the medical silicone antifoam type which is well-known in the art, and which will not wash off in the blood during the debubbling operation. As the blood bubbles contact the defoaming layers, rivulets of

oxygenated blood are formed, and the free oxygen and carbon dioxide are given off and pass outwardly of the upper chamber.

As will be seen, oxygenated blood must pass through a considerable portion of the deforming means and through a filter means in order to reach reservoir 21 and collecting chamber 23. As herein shown, the mesh layers 31 are retained in place about the bubbler assembly 28 by a porous cover or bag 32 preferably formed of nylon material and having a pore size of about 0.125 sq. mm. which filters the blood as it passes out of the bubbler assembly. In the adult size oxygenator, the cover 32 preferably has a surface area of approximately 144 sq. in. The nylon bag 32 is provided with drawstrings 33 at one end which are drawn tightly around the bubbler assembly so that all of the blood flowing out of the bubbler assembly will be caused to pass through the nylon fabric. In the adult size bubbler oxygenator, it is preferred to provide seven layers 31 of the polypropylene fabric, while in the pediatric and infant size the number of layers may be decreased. Between the two outermost layers of the polypropylene mesh material, a polyethylene sheet 34 is positioned so as to extend about the bubbler assembly for nearly 360 degrees. The arcuately disposed lower marginal edge of the polyethylene sheet 34 is normally positioned about one and a half to two inches upwardly of the lower end of the oxygenator chamber 20, and the upper arcuate marginal edge of the sheet 34 is located approximately the same distance from the upper end of the oxygenator chamber 20. The purpose of the polyethylene sheet 34 is to form a trough-like formation for the debubbled blood so that this blood is caused to flow angularly downwardly through the mesh layers 31 within the sheet 34 to maximize the debubbling operation. Also, as will later be explained, the sheet 34 causes the blood to gradually flow to the lower end of the oxygenator chamber so as to make a smoother entrance into blood in the central chamber 21. If the sheet 34 were not present, some of the debubbled blood may drip down and splash on blood collected in the central chamber 21 so as to cause undesirable bubbling.

The excess free oxygen from the bubbling operation and the oxygen and carbon dioxide emitted in the debubbling or defoaming operation escape from the oxygenating chamber 20 through vents 35. If desired, the cap containing vents 35 may be spaced from the exhaust port to provide annular vents also. As best seen in FIGURES 1, 2 and 4, a number of pairs of arcuate indented ribs 36 are positioned to bear against the nylon bag 32 and the layers 31 so as to space intermediate portions of these members from the inner lateral surface of the oxygenator chamber 20, thereby preventing the outer surface of the nylon bag from bearing against the inner lateral surface of the oxygenator chamber 20 in partially sealing relation. Thus gases are free to escape outwardly through the nylon bag, then upwardly to the top of the oxygenator chamber 20, and finally longitudinally outwardly of the chamber 20 between the inner spaced ends 36a of each of the pairs of ribs 36 (FIGURE 2) to the vents 35. The gases may also escape to the vents 35 from between the upper end of the nylon bag 32 and the inner face of the upper end of the oxygenator chamber 20, as shown in FIGURE 4.

As best seen in FIGURE 4, short indentations 42 are preferably formed as the lower end of the chamber 20 to afford end supports for the nylon bag 32 and thereby space the bag from the elongated narrow open upper end 43 of the central chamber 21. Thus the nylon bag 32 when wetted with blood will be prevented from lodging in sealing engagement with the open end or slot 43.

The narrow central or intermediate chamber 21 provides a kind of reservoir for the oxygenated blood. The central chamber has side wall portions 38a, 38b, which are generally parallel and rather closely spaced. The side wall portions 38a, 38b are joined to the larger side wall portions 40a, 40b by diverging side wall portions 41a, 41b.

The side wall portions 40a and 40b are also generally parallel but, because of the diverging side wall portions 41a and 41b, are spaced farther apart than are the side wall portions 38a and 38b. Thus the lower end of the central chamber or reservoir 21 accommodates a small volume of oxygenated blood and will fill rather rapidly in use so that during use the level of the blood will preferably extend into the lower end of the upper oxygenator chamber 20 (see FIGURES 1 and 4) and inundate the lower marginal edge of the sheet 34.

The lower mating portions of shells 25, 26 afford the lower cylindrical chamber 22, and the shell portions are provided with indented pairs of arcuate ribs 44, the corresponding pairs in each shell portion being positioned in a plane extending at an acute angle to the axis of the lower chamber 22, as shown in FIGURE 1. The central chamber 21 communicates with the cylindrical chamber 22 through a narrow elongated slot 45 extending substantially the full length of the chamber 22.

The lower chamber 22 houses a water jacket 46 which makes a close fit with and abuts the arcuate ribs 44 so as to arcuately provide a number of wide shallow passages 49 for blood flow between the outer surface of the water jacket 46 and the inner surfaces of the shells 25, 26, the depth of the passages preferably being on the order of .0065 to .0080 inch.

The water jacket 46 is hermetically sealed at 47, and fittings 48 are provided for connection to a source of temperature control liquid so as to control the temperature of the wide, thin streams of oxygenated blood passing over the outer surface of the water jacket. In the adult size oxygenator, the heat exchanging surface of the jacket 46 preferably has an area of approximately 270 sq. in.

In addition to defining wide, shallow passages 49, the ribs 44 function as a bubble trap for any gas which might on occasion come out of solution. Although the passages are inclined, the blood will tend to flow in a perpendicular direction which creates a minimal backwash along the lower margin of each rib 44 and affords an effective bubble trap. At flow rates over four liters per minute, the pressure has been measured to be about 1 cm. of water less next to the lower margin of each rib 44 than in the center of a passage 49. This pressure differential tends to draw any bubbles upwardly out of blood and against the lower margin of the rib; thereafter hydrostatic pressure causes the bubbles to rise upwardly to the surface of the blood in the central chamber 21 and thence upwardly and outwardly to the vents 35.

From the chamber 22 the temperature controlled, oxygenated blood passes out an elongated port 50 extending the length of the bottom of chamber 21 into the collecting chamber 23. At one end the port 50 is narrowed substantially in width to a very small fraction of an inch as a result of the parallel, closely adjacent finger-like sections 51a, 51b formed in shells 25, 26, respectively. Thus in operation of the device, the narrow end of port 50, which is positioned lower than the remainder of the port, will accommodate only a relatively small amount of blood flowing therethrough; and therefore the blood does not flow preferentially only around the lowermost part of jacket 46 but also flows about upper parts of the jacket to make maximum use of the inclined heat exchanging surface of the jacket. A small passage is also preferably provided extending from the extreme bottom corner of the heat exchange chamber to the collecting chamber to assure complete drainage of the heat exchange chamber. From the collecting chamber 23 the oxygenated blood is conducted through the discharge ports in the fittings 52a, 52b to the arterial system of the patient.

THE BUBBLER ASSEMBLY

The bubbler assembly 28 is best shown in relation to the remainder of the structure in the oxygenating chamber 20 in FIGURE 4. Broadly, the function of the bubbler assembly is to bubble jetting streams of oxygen

through incoming venous blood so as to create thin films of blood in bubble form in an oxygen atmosphere. The oxygen atmosphere exists within each of the blood bubbles, and the thin films of venous blood exposed to the oxygen effects a transfer of oxygen gas to the hemoglobin in the blood and the consequent release of carbon dioxide from the hemoglobin of the blood. The structure of the instant bubbler assembly has proven to be extremely efficient in actual use, and has shown a capability of being able to maintain substantially a hundred percent saturation of oxygen in the blood throughout many hours of continuous use at flow rates of oxygenated blood exceeding five liters per minute.

The detailed structure of the bubbler assembly 28 is best shown in FIGURES 5-12 and all parts of the bubbler assembly are preferably formed from polycarbonate plastic material referred to previously. Referring to FIGURE 5, the bubbler assembly 28 includes a hollow elongated housing, generally designated 60, which affords an internal chamber, generally designated 61. A closure plate 62 carries venous blood inlet means, generally designated 63, and an oxygen inlet means, generally designated 64. The closure plate 62 has a peripheral flange 62a, which is adhered to the proximal end of the upper chamber 20 by suitable adhesive to provide an air-tight seal. The other end of the bubbler assembly 28 is provided with a covering member, generally designated 65, which is mounted on the other or distal end of the housing 60. The covering member preferably is generally shaped in an umbrella-like fashion, and it is provided with an annular peripheral overhanging portion 66, which is spaced forwardly and outwardly of the end of the housing 60 so as to afford an outlet means for blood bubbles, generally designated 67, through a pair of generally arcuate ports 68, positioned on opposite sides of the housing 60.

The internal chamber 61 of the housing 60 is provided with partition means, generally designated 70 (see FIGURES 7, 9 and 12), which divides the internal chamber into a continuous closed passageway 71 having a length which is substantially of a uniform cross section from the inlet means to the outlet means. As herein shown, the passageway includes an upper segment 72 which extends forwardly of the bubbler assembly into a U-shaped connecting segment 73, which in turn joins and communicates with a lower segment 74 extending along the bottom of the housing 60 toward the inlet means 63. The lower segment 74 in turn communicates with a central segment 75, which extends forwardly of the housing to the arcuate outlet ports 68. The central segment 75 is preferably bisected by a central web 76 of the partition means 70 so as to form a pair of central branch segments 75a, 75b.

As can best be seen in FIGURES 4, 5, 6 and 9, the blood inlet means 63, the oxygen inlet means 64, and the closure plate 62 are preferably formed from a pair of plastic mating parts, generally designated 77, 78. The part 77 is preferably injection molded from polycarbonate or similar plastic stock, while the part 78 is preferably vacuum formed from a similar type material.

The blood inlet means 63 is formed in the part 77 and includes a pair of hollow fittings 80, 81, which empty into a common blood inlet port 82 formed by the annular tube 83. The fittings 80, 81 and the annular tube 83 are integrally formed in an annular end wall member 84, which is provided at its peripheral marginal edge with a continuous annular side wall member 85 to form an annular oxygen inlet chamber 86 about the annular tube 83. A hollow oxygen inlet fitting 87 opens through the end wall member 84 into the chamber 86.

The part 78, which includes the closure plate 62, is preferably formed with a second annular side wall member 88 and with an integral cone-shaped wall member 90, which extends rearwardly and terminates in an inlet blood aperture 91 formed by a ring-like rearward projection 92. As best seen in FIGURE 9, the outer lateral surface of the side wall member 85 tapers inwardly so as to tele-

scope into a close sliding fit within the inner lateral surface of the second side wall member 88, and the ring-like projection 92 is of a size to make a close telescoping fit within the end portion of the annular tube 83. In assembly, the parts are permanently adhered together by a suitable adhesive.

Thus the end wall member 84, the side wall members 85, 88, and the cone-shaped wall member 90 form an oxygen inlet chamber 86, which chamber is separated from the inflowing venous blood passing through the port in annular tube 83 centrally of the oxygen inlet chamber 86.

The forward portion of the second side wall member 88 in turn telescopes within the open end of the housing 60 and in assembly is secured in place by a suitable adhesive.

The cone-shaped wall member 90 has one portion in which there are arcuately disposed a plurality of minute apertures 93 through which oxygen is admitted into the housing 60. As herein shown, the inner surface of the cone-shaped wall member 90 has 150 apertures, each approximately .013" in diameter. The apertures are preferably arranged in increasing arcs in the surface of the cone-shaped wall member 90, there being six arcs of varying radii and 25 apertures in each arc.

As can be seen in FIGURES 4, 9 and 10, the inner surface of the cone-shaped wall member 90 actually provides a divergent mouth for the blood inlet port 92 so that, as the incoming venous blood diverges in a wide shallow stream, the blood is immediately bubbled by the multitude of tiny jetting streams of oxygen directed transversely of the flow of blood. The structural arrangement is such that substantially all of the incoming blood is immediately formed into bubble films so that complete exposure of the blood in film form to an oxygen atmosphere is immediately accomplished.

As seen in FIGURE 4, the housing 60 is upwardly inclined when in operative working position. The blood bubbles initially formed in the bubbling chamber 94 are guided upwardly by inclined surface 95 into the upper passageway segment 72 which is somewhat trough-shaped (FIGURE 7). Within segment 72 some bubbles may burst and reform droplets of blood while still other small quantities or droplets of blood may be carried along in the upward progress of the bubbled blood in the segment 72. However, as droplets of blood form, the droplets gradually gather together and flow back downward by gravity into the bubbling chamber 94 once more where the blood is again rebubbled and moved once more up the passageway of segment 72. At the forward end of segment 72, inwardly directed surfaces 96 converge the bubbles slightly into the U-shaped connecting segment 73. It should be noted that thorough intermingling of the bubbles occurs at this juncture because, if there is any laminar flow, the lighter strata of bubbles will be forced to flow through the heavier bubbles giving a thorough admixture to the entire flow.

The flow of blood bubbles then passes from the connecting segment 73 downwardly through the lower passageway segment 74 and out opening 97. The bubble flow is then divided by a projecting fin 98 into each of the central branch segments 75a, 75b, and finally baffles 100, 101 deflect the bubble flow outwardly into a pair of cavities 102, 103 between the covering member 65 and the housing 60. The blood bubbles then emerge from each of the arcuate ports 68 so as to pass outwardly and downwardly of the exterior of the housing 60 into contact with the defoaming means 30 which converts the blood bubbles into droplets and then rivulets of blood passing therethrough as explained earlier.

A preferred arrangement for forming the housing 60, the covering member 65, the outlet means 67 and the partition means 70 is shown in FIGURES 9, 11 and 12. Each of the above parts is likewise preferably vacuum formed from a polycarbonate plastic or similar material.

The partition means 70 is actually formed from a pair

of thin inner shell members 70a, 70b, which parts are identical except they are mirror images of each other. Each of the shell members is provided with a continuous longitudinally extending planar flange 110a, 110b. When the two shell members 70a, 70b are adhered together by their mating flanges, by the central webs 76a, 76b, and by the projecting fins 98a, 98b, a U-shaped passageway is provided which forms the upper passageway segment 72, the connecting segment 73, and the lower segment 74 and certain other surfaces and openings previously discussed (see FIGURE 12).

The outer shell members 60a, 60b are likewise mirror images of each other and are likewise provided with flanges 111a, 111b, each of which is coplanar and adapted to mate when the shell members are placed together. In assembling the housing 60, the shell members 60a, 60b are placed about the partition means 70 so that the arcuate lateral surfaces 112a, 112b nest closely against the inner lateral surface of the shell members 60a, 60b; and the inner lateral surface of the shell members 60a, 60b cooperate with the channel members 113a, 113b to form the closed central branch segments 75a, 75b, which were described above.

Furthermore, the assembled partition means 70 converges at its closed forward end 114 and, with the shape and position of the covering member 65, provides the end cavities 102, 103 and the arcuate outlet ports 68. The covering member is joined to the housing by narrow connecting strips 115 and by the common flanges 111a, 111b.

Thus the rather detailed and intricate mechanism of the present bubbler assembly can actually be formed from only six plastic parts. The adhering of the bubble assembly together can be effectively and quickly done during assembly, and the completed bubbler assembly provides for the first time a thoroughly dependable oxygen bubble unit which will assure complete oxygen saturated blood for the most arduous surgical operations.

In operation, the oxygen requirement for the bubbler assembly is generally regulated to be approximately two to five times the venous blood input by volume. Thus if the perfusion rate of blood through the oxygenator is about three liters per minute, then the rate of incoming oxygen is generally between six to fifteen liters per minute. In the majority of situations, the preferred blood-oxygen ratio is approximately 2:5; that is, for every two liters of blood per minute, approximately five liters of oxygen per minute are used.

As pointed out earlier, the bubbler assembly also provides for a thorough admixture of lighter and heavier blood bubbles during their flow through the passageway of the assembly. The heavier bubbles generally have a thicker film or "skin" than lighter bubbles, which tends to slow up oxygen transfer or respiratory exchange because oxygen will diffuse more slowly through a thick film of blood plasma in getting to the hemoglobin. Accordingly, by mixing the heavier and lighter blood bubbles on two occasions in the circuitous passageway of the bubbler assembly, the film or "skin" of the heavier bubbles is altered by bubbles combining to form new bubbles having thinner films thus enhancing and speeding the respiratory exchange.

The rate of flow of blood bubbles upwardly through the bubbler assembly is dependent upon the flow of oxygen and also upon the height differential between the oxygenator and the patient. In other words, the physician (by suspending or securing the oxygenator upon an adjustable standard) can regulate the "head" of blood and therefore the rate of flow. The bubbler assembly of the present invention has shown a unique ability to accommodate extremely high perfusion rates of blood flow required in serious chest surgery and to assure complete respiratory exchange and oxygen transfer at those rates. Thus the present bubbler assembly, by its greatly improved efficiency, has solved a long-existent problem in prior oxygen bub-

blers in which high perfusion rates of blood flow (e.g., five to six liters per minute) has resulted in substantial quantities of unoxygenated blood passing through such prior bubblers to the patient because of the inability of such bubblers to efficiently handle such high flow rates.

The improved defoaming means also aids in assuring the maintenance of high flow rates of blood because of the improved defoaming action of the defoaming means. In addition to providing improved efficiency, the structure of the present defoaming means is atraumatic to the blood hemoglobin thus minimizing damage to red blood cells in their passage through the defoaming means. Just as in the bubbler assembly, the smooth, round fiber of the knitted polypropylene material has no sharp edges to engage and damage the hemoglobin in its passage therethrough. The layers of defoaming material and knitted nature of the material assures a large surface area of potential contact of the defoaming agents with the film of blood bubbles so that substantially all of the bubbles are removed from the oxygenated blood. Furthermore, the enclosing nature of the knitted layers and the covering filter about the bubbler assembly cause and assure that substantially all blood bubbles come in contact with the defoaming agent before entering the central reservoir or chamber.

The foregoing detailed description has been given for clearness of understanding only, and no unnecessary limitations should be understood therefrom as some modifications may be obvious to those skilled in the art.

We claim:

1. In a blood oxygenator device, a bubbler assembly for forming films of blood in bubble form by directing oxygen into a stream of venous blood to cause the transfer of oxygen to the films of blood and the release of carbon dioxide from the films of blood, comprising: a hollow elongated housing affording an internal chamber for confining the flow of blood bubbles in a predetermined path; inlet means for venous blood at one end of the housing communicating with said internal chamber; outlet means at the other end of the housing for the passage of blood bubbles outwardly of the bubbler assembly; and oxygen inlet means disposed adjacent said blood inlet means, said oxygen inlet means including wall members affording an oxygen inlet chamber adapted for connection to a source of oxygen under pressure, one portion of said wall members being positioned below said blood inlet means and having a spreading surface facing to the interior of the housing positioned to directly receive incoming venous blood for immediate spreading thereof into a shallow stream so that blood entering the blood inlet means will flow over the spreading surface of said one portion, said one portion being provided with a plurality of minute apertures to direct jetting streams of oxygen therethrough from the oxygen inlet chamber into the shallow stream of venous blood flowing over said apertures to form blood bubbles which flow through the internal chamber to the outlet means.

2. A bubbler assembly as specified in claim 1 in which partition means are provided in the housing to divide the internal chamber so as to define a continuous closed passageway for the flow of blood bubbles from the blood inlet means to the outlet means, said passageway having three segments, the first segment extending from the blood inlet means and communicating with the second segment at a position adjacent the other end of the housing, the second segment extending from the other end of the housing and communicating with the third segment at a position adjacent the blood inlet means, and the third segment extending to and communicating with the blood outlet means.

3. A bubbler assembly as specified in claim 1 in which the blood inlet means includes a tubular inlet port positioned to extend centrally through the oxygen inlet chamber, the inner end of said inlet port communicating with the internal chamber of the housing, and the outer end of

the inlet port being provided with a plurality of inlet fittings to accommodate a plurality of sources of venous blood to be oxygenated.

4. A bubbler assembly as specified in claim 1 in which partition means are provided in the housing to divide the internal chamber so as to define a continuous closed passageway for the flow of blood bubbles from the blood inlet means to the outlet means, said passageway having an upper segment, a lower segment and a central segment, the upper segment extending from the blood inlet means and communicating with the lower segment at a position adjacent the other end of the housing, the lower segment extending from the other end of the housing and communicating with the central segment at a position adjacent the blood inlet means, and the central segment extending to and communicating with the blood outlet means.

5. A bubbler assembly as specified in claim 4 in which the partition means includes a central web positioned longitudinally to divide the central segment into a pair of branch segments, and the blood outlet means includes an outlet port for each branch passageway.

6. A bubbler assembly as specified in claim 1 in which the blood inlet means is provided with a tubular inlet port communicating with the internal chamber of the housing, and in which said spreading surface is positioned below and forwardly of said inlet port and is shaped to provide a divergent mouth for said port so that entering venous blood from the inlet port will diverge outwardly in a wide shallow stream across said divergent mouth and be exposed to the jetting streams of oxygen from the apertures to form blood bubbles.

7. A bubbler assembly as specified in claim 6 in which the spreading surface of the one portion of the wall members is shaped to provide a concave divergent mouth, and the apertures are substantially uniformly distributed accurately of said mouth so as to expose substantially all of the wide shallow stream of venous blood to the jetting streams of oxygen.

8. In a blood oxygenator device, a bubbler assembly for forming films of blood in bubble form by directing oxygen into a stream of venous blood to cause the transfer of oxygen to the films of blood and the release of carbon dioxide from the films of blood, comprising: a hollow elongated housing positioned to afford an internal upwardly inclined chamber for confining the flow of blood bubbles in a predetermined path; inlet means for venous blood at one end of the housing communicating with said internal chamber; oxygen inlet means disposed adjacent said blood inlet means for connection with a source of oxygen under pressure, said oxygen inlet means communicating with said internal chamber to form blood bubbles by intermixing oxygen with venous blood; outlet means at the other end of the housing for the passage of blood bubbles outwardly of the bubbler assembly; and a covering member secured to the other end of the housing adjacent to and forwardly of the outlet means, the covering member having an overhanging portion extending transversely outwardly of the housing to direct the flow of blood bubbles through the outlet means and then downwardly of and substantially in contact with the exterior of the housing.

9. A bubbler assembly as specified in claim 8 in which the covering member is generally umbrella-shaped affording a concave inner surface facing the housing, and the outlet means includes a pair of arcuate ports positioned in opposed relation at the other end of the housing, the covering member having peripheral marginal edges overhanging the arcuate ports and the outer lateral surface of the housing to direct the flow of blood bubbles outwardly through the arcuate ports and downwardly of the exterior of the housing.

10. A bubbler assembly as specified in claim 8, in which a fiber sleeve coated with defoaming material is provided, the sleeve having a closed end and an open end and being telescoped over the housing and secured thereto, the out-

wardly extending covering member maintaining the closed end portion of the sleeve spaced outwardly from the housing.

11. In a blood oxygenator device, a bubbler assembly for forming films of blood in bubble form by directing oxygen into a stream of venous blood to cause the transfer of oxygen to the films of blood and the release of carbon dioxide from the films of blood, comprising: a hollow elongated housing affording an internal chamber for confining the flow of blood bubbles in a predetermined path; inlet means for venous blood at one end of the housing communicating with said internal chamber; outlet means at the other end of the housing for the passage of blood bubbles outwardly of the bubbler assembly; partition means provided in the housing for dividing the internal chamber so as to define a continuous closed passageway for the flow of blood bubbles from the blood inlet means to the outlet means, said passageway being of substantially greater length than the straight line distance between the blood inlet means and the outlet means; and oxygen inlet means disposed adjacent said blood inlet means for directing oxygen into the venous blood entering the chamber of the housing through said blood inlet means to form blood bubbles.

12. A bubbler assembly as specified in claim 11, in which the closed passageway is of substantially uniform cross sectional area throughout its length so as to assist in maintaining the blood in bubble form throughout its flow through the passageway.

13. A bubbler assembly as specified in claim 11 in which said passageway has three segments, the first segment extending from the blood inlet means and communicating with the second segment at a position adjacent the other end of the housing, the second segment extending from the other end of the housing and communicating with the third segment at a position adjacent the blood inlet means, and the third segment extending to and communicating with the blood outlet means.

14. A bubbler assembly as specified in claim 11 in which the housing is formed of a material having a natural electrical surface charge of the same electric sign as the natural electrical charge of the blood so that there is no tendency for the blood to adhere to the surface of the passageways in the housing.

15. A bubbler assembly as specified in claim 11 in which said passageway has an upper segment, a lower segment and a central segment, the upper segment extending from the blood inlet means and communicating with the lower segment at a position adjacent the other end

of the housing, the lower segment extending from the other end of the housing and communicating with the central segment at a position adjacent the blood inlet means, and the central segment extending to and communicating with the blood outlet means.

16. A bubbler assembly as specified in claim 15 in which the partition means includes a central web positioned longitudinally to divide the central segment into a pair of branch segments, and the blood outlet means includes an outlet port for each branch passageway.

17. A bubbler assembly as specified in claim 11 in which a filter sleeve and a sleeve of mesh fibers coated with defoaming material are provided, each sleeve having a closed end and an open end with the sleeve of mesh fibers being nested within the filter sleeve, the nested sleeves being telescoped over the outlet means of the housing and being secured about the housing so that blood bubbles must pass through the nested sleeves in passing outwardly of the outlet means of the housing.

18. A bubbler assembly as specified in claim 17 in which a flexible sheet impervious to blood is provided within the filter sleeve, said sheet extending substantially the entire longitudinal length of the nested sleeves and being positioned to form a trough-like member to receive debubbled blood and to direct debubbled blood in a gradual flow toward the end of the nested sleeves secured to the housing.

19. A bubbler assembly as specified in claim 17 in which the sleeve is formed of a plurality of layers of the mesh fibers, the mesh fibers being formed of polypropylene and being generally rounded and smooth so as to minimize trauma to the hemoglobin of the blood.

20. A bubbler assembly as specified in claim 19 in which the mesh fibers are knitted so that the knitted layers afford a multiplicity of tortuous paths of flow for the blood and blood bubbles passing through the sleeve to assure complete debubbling and defoaming of the blood passing through the sleeves.

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MORRIS O. WOLK, Primary Examiner

BARRY S. RICHMAN, Assistant Examiner