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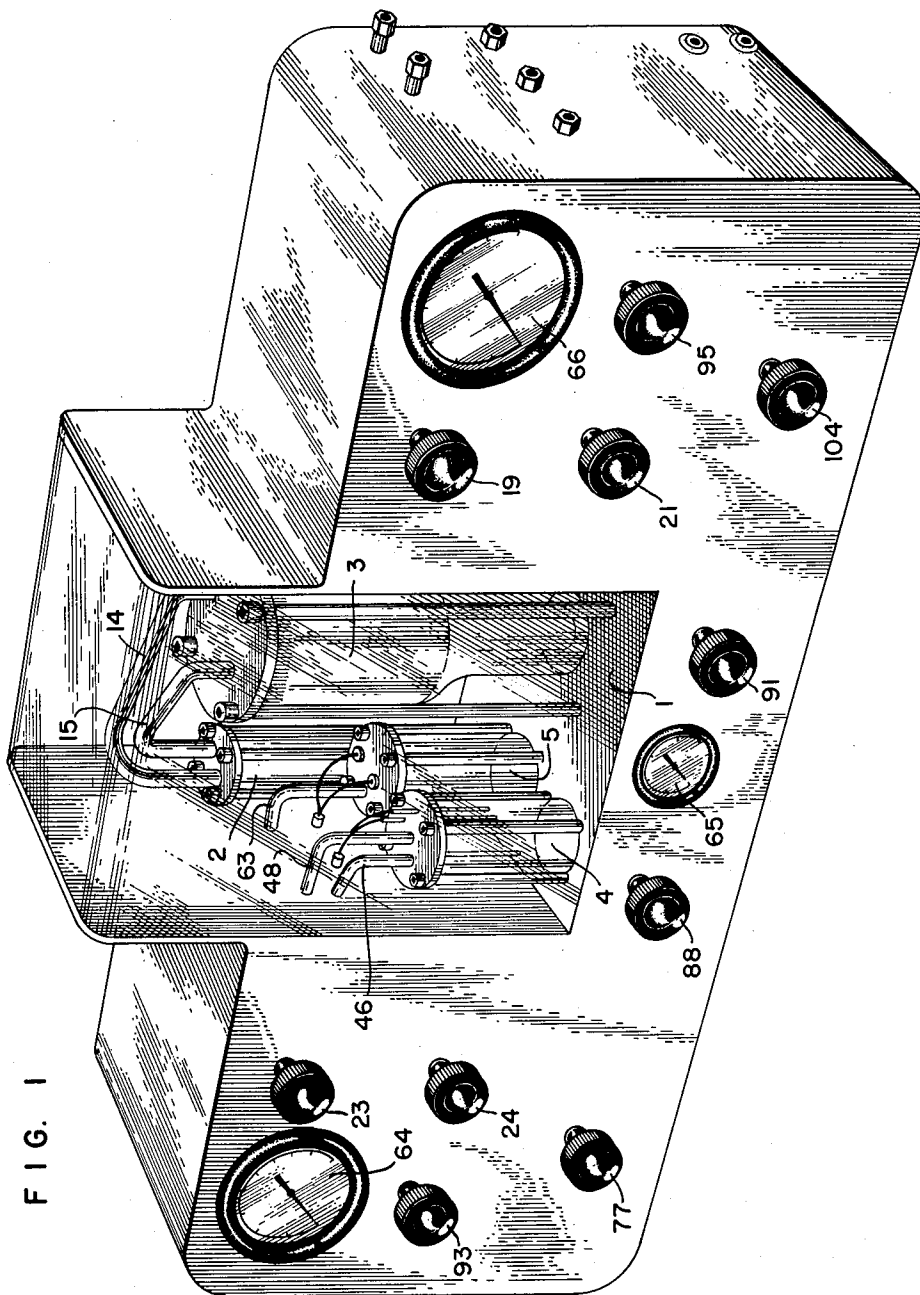
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3,075,524

BLOOD OXYGENATING APPARATUS

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2 Sheets-Sheet 1



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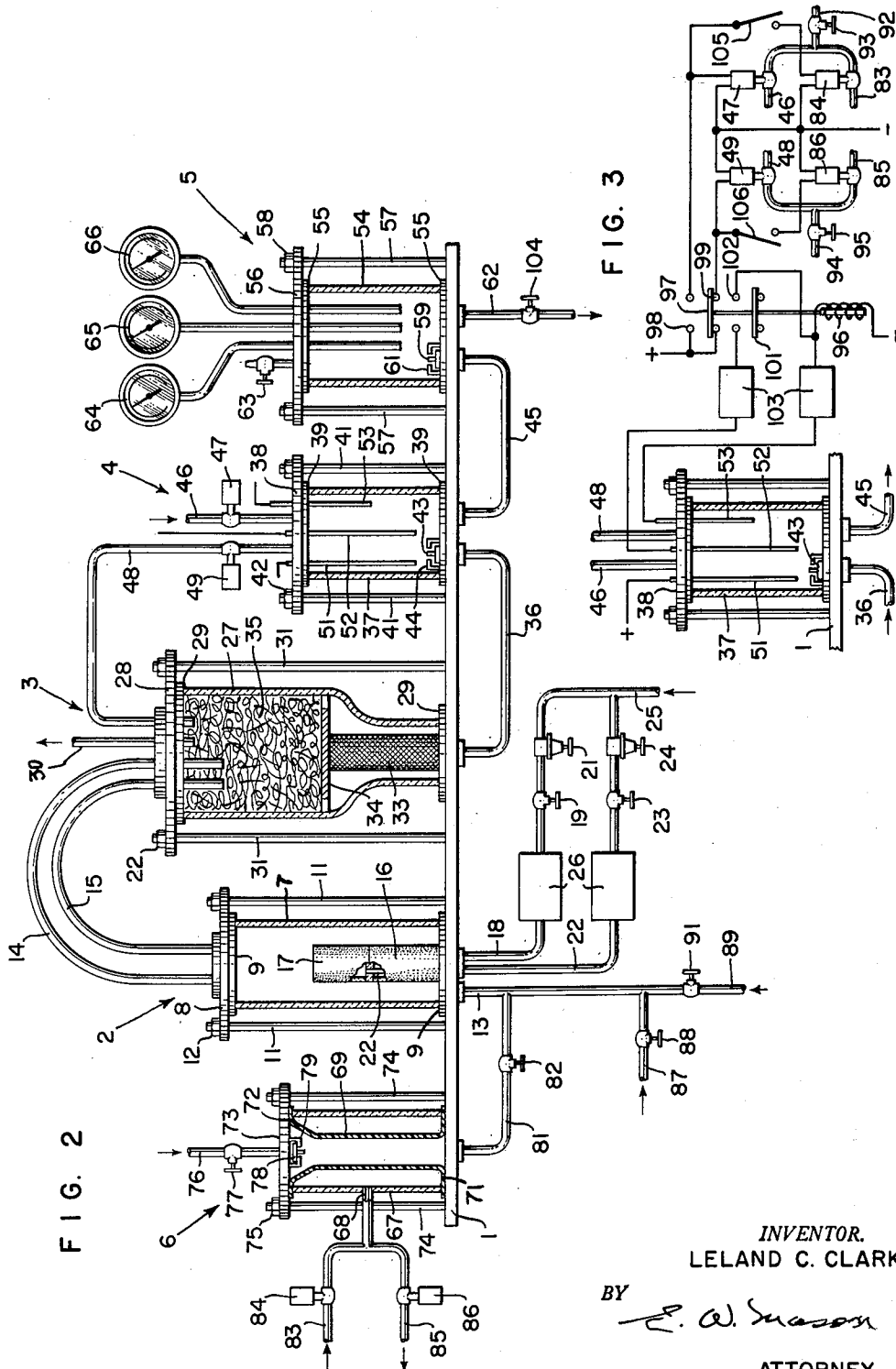
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BLOOD OXYGENATING APPARATUS

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The present invention relates to blood oxygenating apparatus, and more particularly to apparatus of that type which is simple in operation and one which can be easily cleaned and sterilized.

Various types of heart-lung apparatus have been developed for use in heart surgery. All of them with which I am familiar, however, have the disadvantage of requiring several operators and of being so constructed that adequate cleaning and sterilization is difficult, if not impossible. In addition, most apparatus of this type requires a relatively large quantity of donor blood before it can be placed in operation.

It is an object of the invention to provide a blood oxygenating apparatus that is simple to operate, and one in which the various components can be grouped together so that the controls therefor are readily accessible.

It is a further object of the invention to provide an apparatus in which the parts thereof may be readily disassembled for cleaning and sterilization.

It is a further object of the invention to provide a blood oxygenating apparatus which requires only a small amount of donor blood to place it in an operating condition.

The apparatus includes means for oxygenating blood, removing the foam produced thereby and pumping it from and to a patient. In addition there are provided instruments for measuring the variables that are encountered.

The various features of novelty which characterize my invention are pointed out with particularity in the claims annexed to and forming a part of this specification. For a better understanding of the invention, however, its advantages and specific objects attained with its use, reference should be had to the accompanying drawings and descriptive matter in which I have illustrated and described a preferred embodiment of the invention.

In the drawings:

FIG. 1 is a view of the assembled apparatus

FIG. 2 is a view, partly in section, showing the various components and how they are connected, and

FIG. 3 is a wiring diagram showing the control for the pump.

Referring to FIGS. 1 and 2 it will be seen that the various elements of the apparatus which are contacted by the blood during its operation are mounted on a supporting plate 1 that is preferably of polished stainless steel, as are all of the metal parts. The various elements of the apparatus include an oxygenator 2, a defoamer 3, a pump 4 and a surge chamber and reservoir 5. If desired, there may also be included a cardiac pump 6. The various units comprising the apparatus are connected by tubing formed of a flexible, inert plastic that can be sterilized. In the following description the construction of the parts will first be described. This will be followed by a description of the connections and of the operation of the apparatus.

The oxygenator consists of a glass cylinder 7 and a top plate 8. Washers 9, of some suitable resilient inert material, are placed between the lower end of the cylinder and plate 1, and between the upper end of the cylinder and top 8. The parts are held in place by means of rods 11 that are threaded into plate 1 with the top being held on the rods by nuts 12. When the nuts are screwed down on the rods the washers will be compressed by the cylinder

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in order to form a pressure tight chamber. Blood is introduced into the cylinder by a tube 13, and leaves the top of the cylinder through parallel tubes 14 and 15. Each of these tubes is connected to its respective plate by a suitable pressure tight connection that can be easily disconnected.

Oxygen is introduced into the chamber for the purpose of oxygenating the blood through a pair of hollow, porous cylinders 16 and 17. Cylinder 16 is about 1 inch in diameter and 4½ inches long and has a maximum pore size of 6 microns so that oxygen passes through the pores to create tiny bubbles in the blood. Oxygen is introduced into this cylinder through a pipe 18 that has in it a manually operated valve 19 and a pressure regulator 21. The porous cylinder 17 is about 1 inch in diameter and 1 inch long with larger pores having a maximum pore size of 40 microns and introduces the oxygen in larger bubbles into the blood. Oxygen is supplied to the interior of cylinder 17 through a pipe 22 having in it a manually operated valve 23 and a pressure regulator 24. Both pipes 18 and 22 are supplied from a suitable source of oxygen from pipe 25. The cylinders 16 and 17 are about half the diameter of cylinder 7 so that there is thorough mixing of the blood and oxygen around them as well as between the top of cylinder 17 and the top of the chamber. It is noted that the oxygen may be humidified, if it is desirable for a particular operation, by means of conventional humidifiers 26 that are located in pipes 18 and 22.

The oxygenated blood, which is usually foaming, leaves the oxygenator through tubes 14 and 15 to enter the defoamer 3. This defoamer is comprised of a glass cylinder 27 having a large upper and a relatively smaller diameter at its lower end. This cylinder is held tightly against plate 1 by means of a top plate 28 with washers 29 between the ends of the cylinder and plates 1 and 28. The plate 28 is held in position to compress the washers by means of rods 31 that are threaded into plate 1, and nuts 22 that are threaded upon the upper ends of rods 31. Located in the bottom of cylinder 27 is a strainer 23 that is preferably made of stainless steel mesh. This strainer has resting on its upper end a disc 34 that is provided with slots around its outer edge. The disc serves to support the mass of ribbon made of a plastic material that is inert with respect to oxygen and blood, and which has been treated with a defoaming agent. The interior of the defoamer is connected with a vacuum at all times through a tube 30.

Blood leaves the defoamer through a tube 36 to enter into the pump 4. This pump also consists of a glass cylinder 37 that has a top 38 which forces the ends of the cylinder against washers 39. This is accomplished, as in the previous elements, by means of rods 41 that are threaded into plate 1 and nuts 42 threaded onto the upper ends of the rods. Blood is introduced into cylinder 37 past a check valve 43 that is held in position over the entrance by a cage 44, and the blood leaves the pump chamber through a tube 45.

The blood is sucked into and forced from the pump chamber by means of the alternate application of a vacuum and a pressure to this chamber. The pressure is introduced through a tube 46 having solenoid valve 47 in it while the vacuum is applied from the defoamer through a tube 48 having a solenoid valve 49 in it. Opening the valve 49 equalizes the pressures in chambers 37 and 27, the latter of which is connected by tube 30 to the vacuum. The control of the application of the pressure and vacuum is applied in a manner, to be described later, through electrodes 51, 52 and 53 which are inserted in the pump chamber through the top 38.

Blood leaving the pump chamber through tube 45 goes to the surge tank and reservoir 5 that is composed of a

glass cylinder 54 the ends of which are forced against washers 55 by means of a top 56. This top is held in position on rods 57 that are threaded into plate 1 by nuts 58 on the upper ends of the rods. The blood enters from tube 45 through a check valve 59 that is held in position by a cage 61. The blood leaves this reservoir through a tube 62 having a valve 104 in it.

Since at this point the blood has been oxygenated, and is ready for delivery into the arteries of a patient, its properties can be measured by instruments 64, 65 and 66 that are adapted, respectively, to measure the pO_2 , temperature and the pH of the blood.

In some types of operations it is desirable to have a pump to remove cardiac blood and recirculate it directly to the patient or through the oxygenator. In order to be able to accomplish this result the apparatus is provided with a cardiac pump 6. This pump includes a glass cylinder 67 having an opening 68 formed in its side. Within this cylinder is a flexible tube 69 that has a flaring lower end 71 which extends between the lower end of cylinder 67 and plate 1. Tube 69 also has a flaring upper end 72 that is clamped between the upper end of cylinder 67 and a top 73. The top is moved against the ends of the tube 69 and is held in position thereon by rods 74 which have nuts 75 on their upper ends. Blood is introduced into the flexible chamber formed by tube 69 from a cardiac supply through tube 76 having a valve 77 therein. Between the tube 76 and the chamber there is provided a check valve 78 that is held in position by a cage 79. Blood leaves the chamber formed by tube 69 through a tube 81 that is shown as being connected with inlet 13 of the oxygenator. This tube is provided with a check valve 82. Blood is pumped through the tube 69 by the alternate application of pressure and vacuum around its outer surface. To this end the opening 68 is connected with a pressure supply 83 through a solenoid valve 84 and with a source of vacuum through a line 85 having a solenoid valve 86 in it.

Blood is supplied to the apparatus in order to prime it before use from a source of donor blood connected with pipe 87 having a valve 88 in it. During an operation venous blood is supplied to the apparatus through a pipe 89 having a valve 91 in it.

It is intended that the pressure supply for both pump 4 and pump 6 be supplied from the same source, that is preferably oxygen which is also used to supply the oxygenator through pipe 25. It is also intended that the vacuum for pumps 4 and 6 be connected to the same vacuum pump that is connected to tube 30. The various solenoid valves that are used in operating the apparatus are connected to and operated in the proper sequence through an electrical relay system that depends upon the level of the blood in the pump chamber formed by cylinder 37. Referring to FIG. 3, there is shown a pressure supply pipe 92 extending through a valve 93 to the inlet of valves 47 and 84. There is also shown a pipe 94 connected to a vacuum pump that extends through a valve 95 to the inlet of solenoid valves 49 and 86. The valves are actuated by a relay 96 that is in turn energized or deenergized in accordance with the level of the blood in the chamber of pump 4. The relay has a contact bar 97 that, when in its upper position, bridges contacts 98 to energize valves 47 and 84, and which bridges contacts 99 in its lower position to energize valves 49 and 86. The relay is also provided with a contact bar 101 that will, under circumstances described below, bridge contacts 102 to form a holding circuit for the relay. Since it is inadvisable to pass a large current through electrodes 51, 52 and 53 that contact the blood and control energization of relay 96, it is desirable to have amplifiers 103 in the lines connecting the electrodes and the relay. Since, in some cases, it may not be necessary to use cardiac pump 6, switches 105 and 106 are provided respectively in the energizing circuit leading to valves 84 and

86 so that these valves may be operated or not as desired.

In preparing the apparatus for operation regulator 21 is adjusted so that the oxygen supplied to the fine pore diffuser 16 is at a pressure of about 8 p.s.i. and regulator 24 supplying oxygen to the coarse pore diffuser 17 is adjusted to about 4 p.s.i. During the operation of the apparatus the reading on meters 64 and 66 indicating, respectively, the pO_2 and pH of the treated blood will indicate to an operator how valves 19 and 23 should be adjusted. The oxygen flowing through cylinder 16 will be in tiny bubbles that are readily absorbed and control of the oxygen flow through this part will quickly adjust to pO_2 value. The bubbles produced by oxygen flowing through cylinder 17 will be much larger. These bubbles, because of their size, are not as readily absorbed so they help to remove CO_2 , and thereby can be used to control the blood pH value. The temperature of the blood being treated can be raised above or reduced below normal by any suitable apparatus and its temperature will depend upon the type of operation being performed.

The operation of the pump depends upon the level of the blood in the pump chamber. When the blood is below the ends of electrodes 51 and 52 the circuit to relay 96 will be broken. Contact bar 97 will then fall to bridge contacts 99, thus energizing solenoid valve 49 to open it. This equalizes the pressure in the pump chamber 37 with that in the defoamer chamber 23. Blood will then flow from the defoamer, into which it is continuously drawn by the vacuum through tube 30, under its pressure head past valve 43 into the pump chamber until it reaches a level where it engages electrode 53. Valve 59 in the surge chamber will be closed during this time. A circuit is then completed through electrodes 51 and 53 and the coil of relay 96 to energize it. Contact bar 97 will move upwardly to break the circuit through contacts 99 and close a circuit through contacts 98. When contacts 99 are opened, solenoid valve 49 is deenergized to close and cut off the vacuum from the pump chamber. Closing contacts 98 completes a circuit to energize solenoid valve 47 and open it so that pressure can be applied to the pump chamber to drive the blood out through tube 45, valve 43 closing automatically at this time. As contact bar 97 moves upwardly, contact bar 101 will also move upwardly to bridge contacts 102. This completes a holding circuit for the relay coil 96 through electrodes 51 and 52 that will remain closed until the blood level drops below these electrodes. The frequency of operation of the pump can be adjusted by controlling the amount of vacuum and the volume of blood moved during each cycle will vary with the position of electrode 53, which can be moved up and down in top 38.

When the apparatus is operated, it is first primed with donor blood. To this end valve 88 is opened and, since there is no liquid in the system, the reduced pressure applied through pipe 30 and pipe 48 will fill the system. Thereafter blood will be drawn into the oxygenator 2 and defoamer 3 to the pump chamber. As the blood is flowing through the oxygenator it picks up oxygen discharged through 16 and 17. This produces foaming that must be removed. The gas forming the foam is removed through tube 30 as the blood flows through the loosely packed and treated ribbon in chamber 27. Since disc 34 is solid except for the grooves around its periphery, the blood must flow through the ribbon mass and down the sides of the chamber to reach strainer 33. Gas in the form of surplus oxygen and CO_2 removed from the foam is exhausted from the chamber through tube 30. After the apparatus has been primed, valve 88 is closed and valve 89 is opened so that venous blood from the patient can be treated. It will be noted that the vacuum applied to pump 4 is applied through the defoamer. This is a decided advantage since the variable pressure produced in the defoamer as valve 49 is opened and closed assists in the defoaming action. As the oxygenating

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process takes place under a reduced pressure, the possibility of putting too much oxygen in the blood is reduced.

Blood moves from pump 4 into the surge tank, and from there through tube 62 as arterial blood to the patient. Blood flowing into the surge tank through valve 59 can move directly out through tube 62. Usually, however, blood is forced into the chamber by the pump faster than it can flow out so that the blood level in the chamber rises compressing the gas in the upper part thereof. This creates a pneumatic pressure which will increase the flow of blood from the chamber. Thus this chamber serves to reduce somewhat the pulsations that are set up by the pump, and at the same time applies some pressure to the blood being supplied to the patient. An additional, and important function served by this chamber is that any free gas carried by the blood can rise to the surface in this chamber and a final separation take place. Vent 63 can be opened from time to time to relieve the pressure in the upper part of the chamber, and therefore change the level to which the blood will rise.

If the cardiac pump is to be used to remove blood from the patient during open heart surgery, for example switches 105 and 106 will be closed so that solenoid valves 84 and 86 will be operated in unison with valves 47 and 49 respectively. When valve 86 is opened the annular chamber between rigid cylinder 67 and flexible tube 69 is connected with the vacuum. This will cause the tube to expand and draw blood through tube 76, the other end of which is placed at some convenient location in the patient. Blood will be sucked through this tube past valves 77, which is opened, and 78 into the interior of tube 69. Valve 86 will then be deenergized and shut while valve 84 is opened. This will then cause pressure to be applied to the exterior of tube 69 thereby forcing blood from this tube through check valve 82 into line 13 leading to the oxygenator. This blood can therefore be treated and returned through the system to the patient.

It is noted that by a slight change in the piping arrangement (not shown) blood from cardiac pump 6 can be supplied directly to the arterial outlet 62. If this is done, it is generally desirable to place a defoamer similar to defoamer 3 in the pipe that would extend from valve 82 to pipe 62. The defoamer will remove any foreign matter from the blood before it is returned to the patient. The coronary pump may be run by a timer separate from that used for pump 4 if desired.

From the above description it will be seen that I have provided a compact apparatus for oxygenating blood which requires only enough donor blood to place it in operation to fill the various chambers in parts 2, 3, 4 and 5. The total quantity of blood needed to fill these chambers will vary between 2 and 4 pints depending upon the size of the chamber in defoamer 3. This chamber will vary with the size of the patient, a large chamber being used for an adult, and a smaller one for a child. The amount of blood needed to prime the apparatus is only a fraction of that which is necessary to be used with other devices of this type that are now available. The apparatus can be operated by only one operator since it is small and compact, and all of the controls, which can take the form of knobs, are placed closely together in front of the operator on the control panel as shown in FIG. 1 of the drawing. While it is not necessary, it is desirable that the apparatus be covered with a suitable casing. Another advantage of the apparatus is that that portion of the casing in front of the glass cylinders can be transparent whereby the operator can watch the flow of blood through the various elements and be sure that everything is working properly.

Actually the entire apparatus operates on the differential pressure between that supplied through tube 46 and the blood pressure of the patient. This provides an automatic safety factor for the patient. When the blood pressure in the patient's artery falls, the pump will tend to operate faster, thus increasing the flow of blood.

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Furthermore, this arrangement makes it impossible to pump blood to the patient if the arterial tube is not properly placed within the center of the artery, since the back pressure in the system will build up equal to the pump pressure.

Since each of the components of the apparatus can be readily disassembled, and as most of them are cylindrical in form, they can be easily cleaned and sterilized. The porous elements 16 and 17 are quite inexpensive and so is the ribbon 35 that is used in the defoamer. These parts can therefore be discarded after each use with a minimum of expense.

From the above description it will be seen that I have provided a so-called heart-lung apparatus which is simple in operation, easily cleaned and can be operated by one person. These are features that are not presently available in apparatus of this type.

While in accordance with the provisions of the statutes, I have illustrated and described the best form of embodiment of my invention now known to me, it will be apparent to those skilled in the art that changes may be made in the form of the apparatus disclosed without departing from the spirit and scope of the invention set forth in the appended claims, and that in some cases certain features of my invention may be used to advantage without a corresponding use of other features.

What is claimed is:

1. In a blood oxygenator, the combination of a cylinder open at both ends of rigid transparent material, end plates on and closing the ends of said cylinder, means individually to force said end plates against the ends of said cylinder to form a chamber, a hollow porous element in said chamber, oxygen supply means extending through one of said end plates into said element whereby oxygen may flow through the same into said chamber, means in said end plates through which blood can be introduced into and removed from said chamber and a second hollow porous element in said chamber, said second element having pores of a maximum size different from the maximum size of the pores in said first mentioned element, and means to supply oxygen to the interior of said second element.

2. In a blood-oxygenating apparatus, means forming a substantially cylindrical chamber, a first hollow member having pores of a predetermined maximum size in said chamber, means to supply oxygen to the interior thereof to flow through its pores, a second hollow member having pores of a larger size than said first member, means to supply oxygen to the interior of said second member, means to regulate individually the flow and pressure of each of said supplies of oxygen, means to supply blood to said chamber to be oxygenated therein, means forming an outlet through which oxygenated blood can leave said chamber, and means to remove surplus oxygen and carbon dioxide from the blood after it leaves said chamber.

3. In an apparatus of the class described, means forming a plurality of chambers, tubing connecting each of said chambers in series, means to supply blood to the first of said series of chambers, a first means to supply oxygen in small bubbles to the blood in said chamber, a second means to supply oxygen in larger bubbles in said chamber to oxygenate the blood, a porous mass of material treated with a defoaming agent in the second chamber of said series of chambers to defoam the oxygenated blood, means to apply a reduced pressure to said second chamber to remove the foam forming gas, a strainer in the bottom of said chamber through which blood flows to the next chamber in said series, automatic valves controlling the flow of blood to and from said last mentioned chamber, means alternately to apply a vacuum and a pressure to said last mentioned chamber to draw blood into and force blood therefrom, and means responsive to the level of blood in said chamber to control the application of said pressure and vacuum.

4. In a blood oxygenating apparatus, the combination of a supporting plate, a plurality of glass cylinders, a cap for each cylinder, means individually to clamp said cylinders between said caps and said plate thereby to form a plurality of chambers, means to supply blood through said plate to one of said chambers, means to supply oxygen through said plate to said one of said chambers to mix with the blood therein, conduit means extending through the cap of said one of said chambers into a second chamber through the cap thereof, means in said second chamber to withdraw surplus oxygen from the blood, means in said second chamber to strain the blood, means extending from the down stream of said strainer through said plate to introduce blood from said second chamber through said plate to a third chamber, a one way valve in said last mentioned means operative only to permit blood to flow into said third chamber, means extending through the cap of said third chamber to apply a vacuum thereto to draw blood into said third chamber, means extending through the cap of said third chamber to apply a pressure thereto to force blood therefrom, means extending through said plate to direct blood from said third chamber to a fourth chamber, a one way valve in said last mentioned means operative only to permit blood to flow from said third chamber to said fourth chamber, and means extending through said plate to direct blood from said fourth chamber to a point of use.

5. The combination of claim 4 including means to humidify the oxygen supplied to said one of said chambers.

6. The combination of claim 4 including means in said third chamber responsive to the level of the blood therein to control the application of vacuum and pressure thereto.

7. The combination of claim 4 including means in said fourth chamber responsive to physical charac-

teristics of the blood therein, and means to indicate said responses.

8. The combination of claim 4 including means forming a flexible, cylindrical chamber having a supply passage connected to a source of blood and a discharge passage thereto, a one way valve in each of said passages to permit the flow of blood to and from said flexible chamber, respectively, means forming a rigid annular chamber around said flexible chamber, means to apply alternately a vacuum and a pressure to said annular chamber thereby to force blood through said passages into and out of said flexible chamber, and means to direct blood from said discharge passage to said one of said chambers.

References Cited in the file of this patent

UNITED STATES PATENTS

2,406,207	Desmet	Aug. 20, 1946
2,652,831	Chesler	Sept. 22, 1953
2,733,056	Marky	Jan. 31, 1956
2,792,002	Malmros et al.	May 14, 1957
2,832,294	Rippingille	Apr. 29, 1958
2,854,002	De Wall et al.	Sept. 30, 1958
2,927,582	Berkman et al.	Mar. 8, 1960

FOREIGN PATENTS

769,786	Great Britain	Mar. 13, 1957
989,821	France	May 30, 1951

OTHER REFERENCES

"A Large Capacity, All-Glass Dispersion Oxygenator and Pump." Review of Scientific Instruments, volume 23, No. 12, 1952, pages 748-753.

"A Pulsating Perfusion Apparatus," Journal of Laboratory and Clinic Medicine, volume 32, 1947, pages 300-310.