PUMP OXYGENATOR SYSTEM

Filed Sept. 18, 1961 3 Sheets-Sheet 1

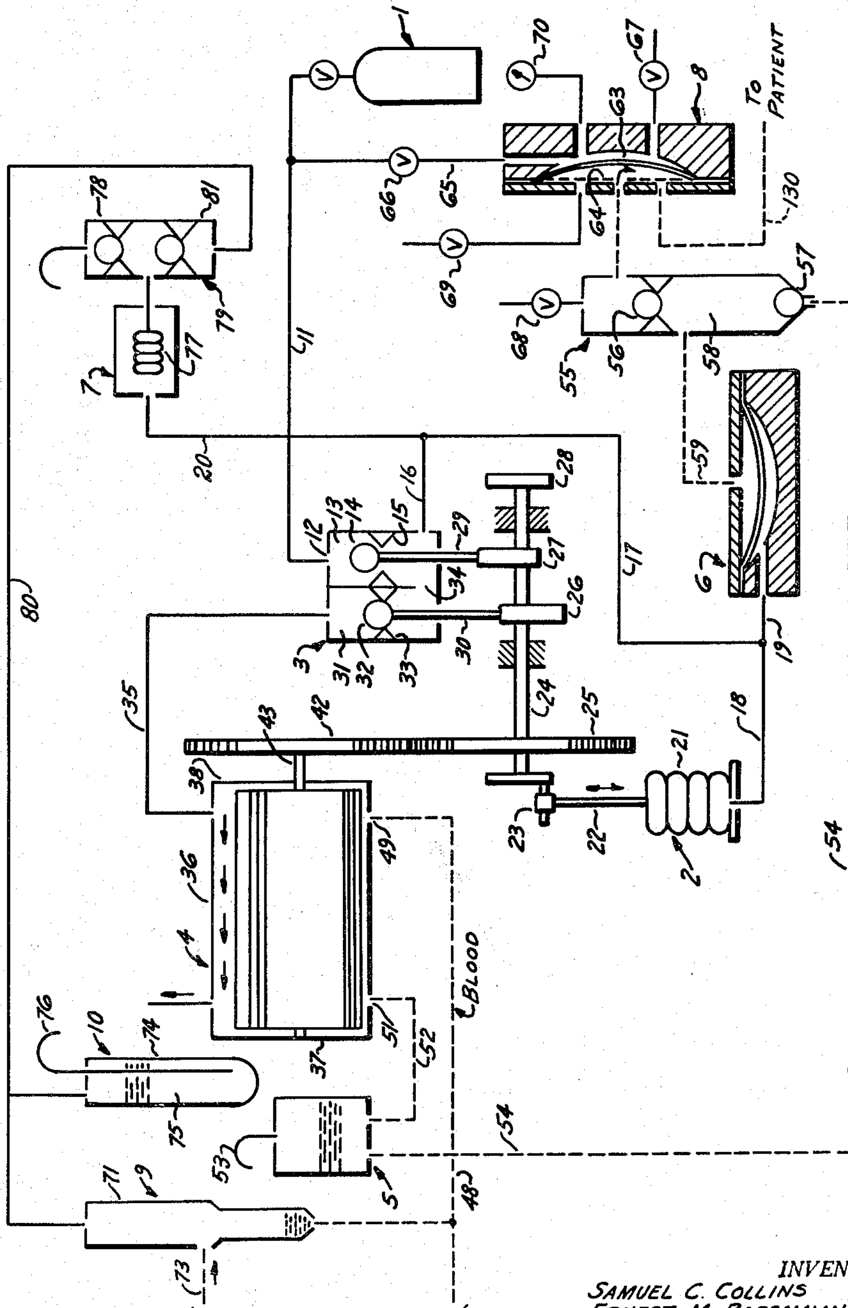

FIG 1

FROM PATIENT

INVENTORS
SAMUEL C. COLLINS
ERNEST M. BARSAMIAN
BY L. L. Shrego.

May 18, 1965 S. C. COLLINS ETAL 3,183,908

PUMP OXYGENATOR SYSTEM

Filed Sept. 18, 1961 3 Sheets-Sheet 2

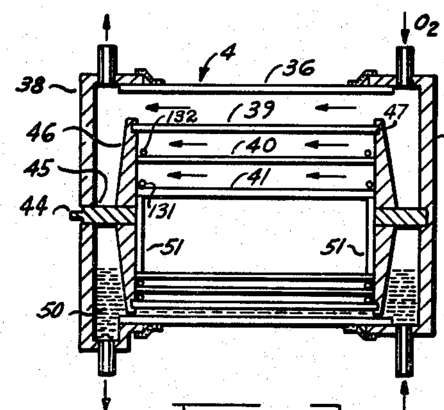

FIG 2

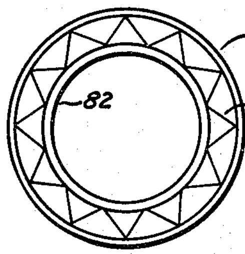

FIG 3

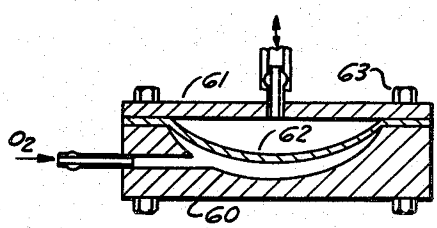

FIG 4

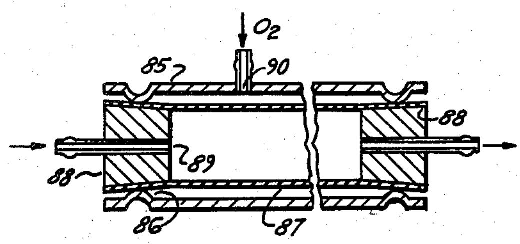

FIG 5

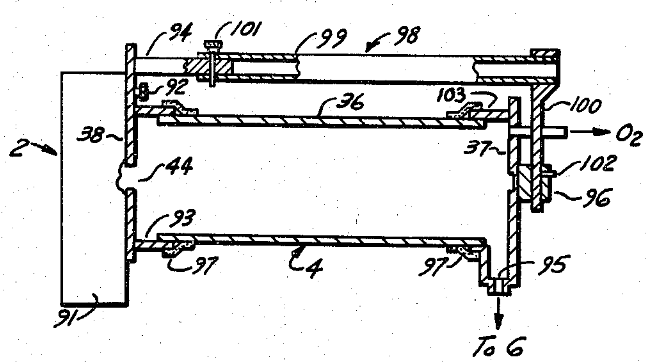

FIG 6

INVENTOR.
SAMUEL C. COLLINS
ERNEST M. BARSAMIAN
BY

PUMP OXYGENATOR SYSTEM

Filed Sept. 18, 1961 3 Sheets-Sheet 3

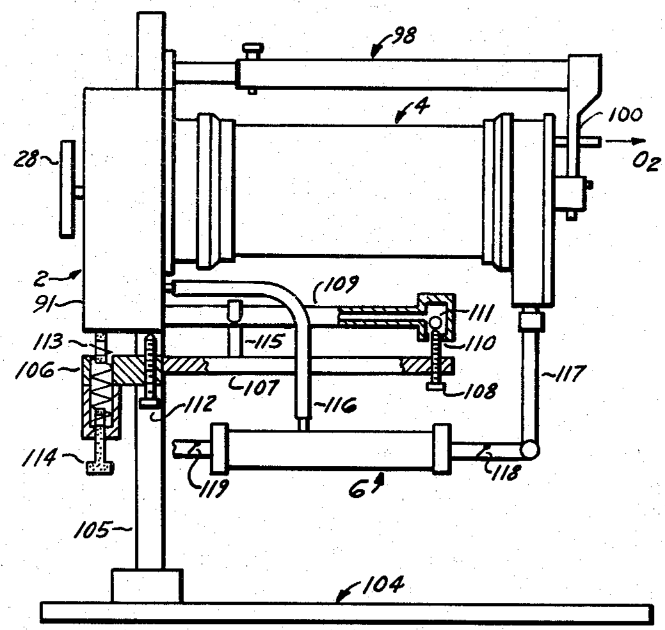

FIG 7

INVENTOR.
SAMUEL C. COLLINS
ERNEST M. BARSAMIAN
BY

United States Patent Office

3,183,908
Patented May 18, 1965

3,183,908

PUMP OXYGENATOR SYSTEM

Samuel C. Collins, Belmont, and Ernest M. Barsamian, West Roxbury, Mass., assignors, by mesne assignments, to the United States of America as represented by the Secretary of the Navy

Filed Sept. 18, 1961, Ser. No. 139,016
16 Claims. (Cl. 128—214)

The present invention relates generally to apparatus for and methods of reproducing the functions of the cardiac and pulmonary organs of a human or animal and, more particularly, to a pump-oxygenator for assuming these vital functions on a temporary basis, such as during open-heart surgery.

In the treatment of certain human ailments, it is oftentimes desirable to relieve the patient's heart and lungs from performing their pumping and oxygenating functions so that surgical repairs to these organs may be performed while they are relatively inactive. Mechanical substitutes for these organs usually take blood from the patient's venous system and first disperse it over a large area in an atmosphere of pure or nearly pure oxygen. After the blood absorbs oxygen in this environment, it is forced by means of a pressure pump into the arterial system of the patient. To be life-sustaining, this process must be continuous and, hence, the pump-oxygenator or heart-lung machine, as it is sometimes called, must process unfailingly a steady stream of blood.

While it is possible to sustain life for hours by means of a pump-oxygenator, even when the heart is completely bypassed, existing machines have certain shortcomings which have so far limited their success. For example, the red corpuscles in blood are often destroyed at a fairly high rate while these machines are in use. Furthermore, a relatively large amount of blood is generally required to fill the pump-oxygenator system. And since this amount cannot be provided by the patient, it must be supplied by donors. Moreover, after each use the apparatus must be disassembled, thoroughly cleaned, and the parts contaminated by blood sterilized and carefully stored for future use. When next needed, these parts, of course, must be reassembled with elaborate precautions taken to insure their sterility.

It is accordingly a primary object of the present invention to provide a pump-oxygenator of simple and reliable construction.

Another object of the present invention is to provide a pump-oxygenator which requires a minimum amount of blood.

A still further object of the present invention is to provide a pump oxygenator wherein the oxygen both oxygenates the blood and furnishes all the motive power required by the apparatus.

A still further object of the present invention is to provide a pump-oxygenator wherein damage to the blood and frothing are minimized.

A yet still further object of the present invention is to provide a pump-oxygenator which derives its blood supply from the patient's venous system and from blood seeping into the operating area.

A still further object of the present invention is to provide a pump-oxygenator having a suction pump which functions with a minimum amount of turbulence whereby little damage or destruction of the red cells of the blood occurs.

A yet still further object of the present invention is to provide a pump-oxygenator wherein compressed oxygen first operates the engine driving the oxygenating apparatus and thereafter oxygenates the blood.

A yet still further object of the present invention is to provide a pump-oxygenator wherein the pump mechanism has a decreasing competence with a decreasing level of blood in the system.

A yet still further object of the present invention is to provide a syphon-type coronary sucker for use in a pump-oxygenating system to augment the blood available from the patient's venous system.

A yet still further object of the present invention is to provide a pump-oxygenator wherein the performance of the pump mechanism is regulated by the level of blood in the oxygenator.

A yet still further object of the present invention is to provide a pumping mechanism for a pump-oxygenating system which can be readily sterilized.

A yet still further object of the present invention is to provide an oxygenator which can be autoclaved as a complete unit.

Other objects and many of the attendant advantages of this invention will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

FIG. 1 is a schematic diagram of the complete oxygenating system according to one embodiment of the invention;

FIG. 2 illustrates the structural details of one type of oxygenator;

FIG. 3 schematically depicts an alternative construction for the rotating component of the oxygenator;

FIG. 4 depicts the general construction of a pressure pump that can be employed in the system of FIG. 1;

FIG. 5 illustrates a flow-through type of pressure pump having similar use;

FIG. 6 illustrates one method of detachably mounting the oxygenator as a complete unit to the engine; and

FIG. 7 shows one general arrangement for automatically controlling the pressure pump in accordance with the level of blood within the oxygenator.

Briefly and in somewhat general terms, one embodiment of the present invention may be seen from an examination of FIG. 1 to comprise a source of compressed oxygen **1**, gas-operated engine **2** of the bellows type driven therefrom, cam-operated ball valve assembly **3** controlling this engine, oxygenator **4**, its reservoir **5**, pressure and suction pumps **6** and **7**, surge chamber **8**, and sucker **9** with its vacuum relief member **10**.

Before discussing the structural details of these devices and the manner in which they cooperate, it would be noted that all of the motive power for the above system is derived from the compressed oxygen and that the expended oxygen oxygenates the blood and acts as a vehicle for removing the carbon dioxide devolved therefrom.

Referring again to FIG. 1, storage tank **1** contains oxygen at a pressure, for example, some ten pounds per square inch above atmospheric pressure and, when the valve controlling this tank is opened, a stream of oxygen flows via line **11** to an entrance port **12** on the top of a first compartment **13** of ball valve assembly **3**. For purposes of description, it will be assumed at this time that ball member **14** in this compartment is off of its seat **15**, permitting oxygen to flow out of main supply line **16** and via branch lines **17**, **18**, **19** and **20** to the base of bellows **21** of engine **2** and to pumps **6** and **7**. Coupled to bellows **21** via rod **22** is a crank assembly **23** which drives camshaft **24** when the above flow distends the bellows. Connected to this camshaft and rotatable therewith are gears **25**, cams **26** and **27** and flywheel **28**. It is these cams acting through push rods **29** and **30** which control the opening and closing of compartments **13** and **31** of the ball valve assembly **3** by raising and lowering ball members **14** and **32** with respect to their seats **15** and **33**. The design of these cams is such that one or the other of these compartments is always open. Consequently, under the conditions assumed, oxygen does not flow at this time from the lower portion of compartment 3 through aperture 34 in the common wall of these compartments and out into line 35 feeding oxygenator 4. It would be pointed out that the weight of balls 14 and 31 is such that the oxygen pressure cannot influence their movement.

As crankshaft 24 rotates, a point in the engine cycle is reached whereat ball 14 descends to its seat 15, preventing the further flow of oxygen into main supply line 16 and the apparatus fed therefrom. Ball 32 is above its seat 33 at this time, opening compartment 31, so that the oxygen stored in the various supply lines and in bellows 21 and pumps 6 and 7 now vents back through these lines, through aperture 34, compartment 31, into discharge line 35 and oxygenator 4 connected thereto. Because of the momentum of flywheel 28, camshaft 24 continues to rotate after bellows 21 has been fully distended, and the mechanical compression of this bellows which occurs at this time in the engine cycle assists the above discharge of oxygen. Engine 2 is thus made ready for the next stroke which occurs when ball valve assembly 3 returns to the condition initially described.

It will thus be seen that the cam-operated valve assembly 3 effectively sets up pulsations in the stream of oxygen emanating from storage tank 1. It is these pressure pulses which also operate pumps 6 and 7 in a manner which will be described hereinafter in greater detail. In one practical embodiment of this invention, pressure changes of one-half atmosphere occurred during the cycle, the pressure at the cylinder being ten pounds per square inch above atmospheric pressure.

The blood oxygenating apparatus, which is generally indicated by reference character 4, is housed within a stationary outer cylinder 36, closed at both ends by plates 37 and 38. This cylinder may be made of glass, for example, with the end plates of stainless steel. Disposed within this cylinder, as best shown in FIG. 2, is a second cylinder 39 of slightly smaller diameter. This latter cylinder rotates about a horizontal axis which is parallel to the axis of symmetry of cylinder 36 but displaced downwardly therefrom so that, while the outer surface of cylinder 39 almost touches the inner surface of cylinder 36 on the low side, a greater clearance exists between these same confronting surfaces on the top side. As illustrated in FIG. 2, two or more additional cylinders 40 and 41 of successively smaller diameter are nested within cylinder 39 with the innermost cylinder of the pair resting on the larger cylinder and this cylinder, in turn, resting on the inner surface of cylinder 39. With this arrangement, whenever the latter cylinder rotates, the two freely supported cylinders also rotate because of friction and the force of gravity.

Cylinder 39 is driven by crankshaft 24 and, more particularly, by gear 25 secured thereto which meshes with gear 42 mounted on one end of drive shaft 43. The other end of this shaft terminates in a spline which mates with a slot cut in a stub shaft 44. A spider 46 having a central hub 45 is mounted on the other end of this stub shaft and, in the particular embodiment shown in FIG. 3, the inner surface of the spokes of this spider is notched at 47 to receive one end of the rotating cylinder 39. A similar spider and stub shaft employed at the other end of the oxygenator complete the drive arrangement. The split drive shaft feature is employed to permit the oxygenator, that is, outer stationary cylinder 36 and the various cylinders housed therein, to be readily detached from the drive portion of the system. This greatly facilitates the sterilization process.

From what has been described hereinbefore, it will be appreciated that oxygen is vented during each cycle of engine 2 via line 35 into the top portion of oxygenator 4 to oxygenate the blood and to carry off the carbon dioxide devolved therefrom. Throughout the operation of the oxygenating system, however, there is a continuous flow of venous blood from the patient via line 48 into the oxygenating apparatus through a lower opening 49 formed in outer cylinder 36. By positioning the patient above the oxygenator, a gravity flow is achieved. Once the venous blood enters the oxygenator, it spreads over the lower surface of cylinder 36 and forms a relatively shallow pool 50 into which all three cylinders continuously dip as cylinder 39 rotates. The blood is thus distributed in thin layers over both the inner and outer surfaces of these cylinders after a few rotations. This dispersal gives a large blood-surface-area-to-volume ratio and results in rapid oxygenation of the blood. In order to reduce the amount of blood needed, both ends of innermost cylinder 41 may be closed off, as shown by plates 51 in FIG. 2. This avoids the necessity of filling the inner portion of the cylinder with blood and increases the level of blood in the oxygenator for a given volume.

Oxygenated blood leaves the oxygenator through opening 51 and flows via U-shaped tube 52 into reservoir 5 vented by tube 53. It will be recognized that by adjusting the relative height of this reservoir the level of blood within the oxygenator can be regulated. From the reservoir the blood flows via line 54 and ball valve assembly 55 into pressure pump 6 which forces it into the arterial system of the patient. The flow of blood to and from this pump is regulated by a gravity controlled valve assembly 55 having balls 56 and 57 which open and close cylinder 58. Lower ball 57 is designed with sufficient mass so that it lifts from its seat only when the level of blood in reservoir 5 or in the vertical portion of line 54 exceeds a predetermined safe level. This feature is a precautionary measure and prevents oxygen from being sucked from oxygenator 4 into pump 6 and being forced thereafter into the patient's circulatory system. Normally, blood will flow into cylinder 58 and thence via line 59 into the top portion of pump 6. This pressure pump, in the simple configuration shown in FIG. 4, comprises a lower base member 60 whose inner surface is concave, a closure plate 61 and a plastic or silicone rubber membrane 62 clamped at its edges between these two members by suitable bolts 63. Both base member 60 and cover plate 61 have passageways cut therethrough to allow oxygen and blood to enter the pump on opposite sides of membrane 62.

It will be appreciated that when the oxygen is vented from the lower portion of pressure pump 6, blood flows into the top portion of the pump via line 59 and displaces membrane 62 downwardly from the position shown in FIG. 4. Thereafter, when the next pressure pulse of oxygen appears, this membrane is driven upwardly, forcing blood back through line 59 and into cylinder 58 to lift ball 56 from its seat and open a passageway to surge chamber 8. In one practical embodiment of the present invention, the oxygenator assembly was elevated above the pressure pump so as to maintain a liquid head of eight to twelve inches on this pump. Whenever the blood level fell below this, ball 57 remained closed and isolated the pump from the oxygenator.

In the modification shown in FIG. 1, pump 6 receives a charge of compressed oxygen and makes one stroke for each cycle of engine 4. It is often desirable to have only one stroke of the pump for several cycles of the engine, and this mode of operation can be readily realized by providing a second camshaft gear driven from shaft 24, the second camshaft turning at lower speed.

Surge chamber 8, which receives oxygenated blood from pressure pump 6, is included in the system to smooth out the flow of blood into the patient's circulatory system. Without this chamber, blood would otherwise be forced into the patient's system in the form of spiked pressure pulses of relatively high intensity. Such pulses would produce turbulence at the entry point which would damage the blood's red cells. In its simplest form, surge chamber 8 can be similar to pressure pump 6, employing a plastic membrane 63 held between two metallic members having the same form as elements 60 and 61. This chamber requires no valves but preferably includes a screen filter 64 positioned on the side of the diaphragm wetted by the blood. This screen is formed with a central aperture through which the blood passes into the upper portion of the chamber. Thereafter, the blood flows back through this screen before it enters discharge line 130 connected to the patient. On the other side of diaphragm 63 there is trapped a volume of oxygen, obtained from storage tank 1 via line 65, which serves as a cushion against the vigorous pulsing of pressure pump 6. The level of pressure in this part of the surge chamber is regulated by valves 66 and 67. Valves 68 and 69 provide means for purging oxygen from the system whenever the priming charge of blood is being added. It has been found that a pressure gauge reading the pressure of the oxygen cushion in the backside of the surge chamber provides an indication of the patient's systolic and diastolic pressures during each cycle of the pump, and pressure gauge 70 is included in the system for this purpose. By carefully monitoring the performance of this gauge, the surgeon can anticipate the need of a blood transfusion.

Suction pump 7, in cooperation with sucker 9, collects blood from the operating area and adds it to that obtained from the patient's venous system. This pump is of low capacity and creates a limited vacuum in vessel 71 at the left side of FIG. 1. Connected to this vessel at a point intermediate its length is a flexible tube 73, the other end of which (not shown) terminates in the blood pool formed by blood leaking from the patient's circulatory system. When the oxygenator is operating, this chamber is kept at a significantly higher level than the venous blood line 48 so that the blood in this line cannot be sucked into the vacuum system. The degree of vacuum obtainable in vessel 71 is controlled by vacuum relief device 10 which consists of a tube 74 containing water or a salt solution 75 and equipped with an air pipe 76 which extends almost to the bottom of the above tube.

When an oxygen pressure pulse enters suction pump 7 via line 29, bellows 77 of this pump is compressed and air is expelled therefrom via the upper valve 78 of ball valve assembly 79 to the atmosphere. Thereafter, when the oxygen in the system is vented, air is drawn into this bellows via line 80 from vessel 71 and from the air space above fluid 75 in relief device 10, the lower valve 81 of ball valve assembly 79 lifting at this time to permit the above flow to take place. After a few cycles of the pump, a negative pressure is thus established in vessel 9, and blood is drawn into this vessel from the operating area via tube 73. Once blood starts flowing between line 73 and venous line 48, it continues because of syphoning action, without regard to the pumping rate of suction pump 7, until the pool of leakage blood is depleted. Thereupon, air enters into the system and breaks the syphon. It would be appreciated that the height of fluid 75 is significant because it establishes the point at which air from the outside will be drawn via tube 76 into the system to limit the negative pressure in vessel 71. During the operation of suction pump 7, there may be a two-phase flow in the suction line 73, slugs of blood and bubbles of air. However, the rate of pumping is so low that blood is not injured by the air drawn into the system. This is in contrast with other types of coronary suckers which are characterized by a very rapid two-phase flow and wherein the turbulence accompanying this flow results in substantial damage to the red cells of the blood.

It would be noted in connection with the oxygenator of FIG. 2 that only a very shallow pool of blood is needed to achieve filming over the inner and outer surfaces of the rotating cylinders. This means, in effect, that the system requires a small priming volume of blood. Moreover, since only a small fraction of these cylinders is under the blood at any one time, almost all of their surface areas are available for oxygenation. In order to minimize foaming of the blood, these cylinders in one practical embodiment of the invention were made of stainless steel and coated with a silicone lacquer which was sprayed on and thereafter baked to give a plasticlike surface. The wall thickness of these cylinders was approximately one-thirty-second of an inch. In order to minimize hemolysis which occurred when the cylinders were rotated at approximately 50 r.p.m., fine stainless steel wires 131 and 132, shown in FIG. 2, were welded around the circumference of cylinders 40 and 41 near each end thereof. This reduced the contact between adjacent cylinders to only two isolated points.

The oxygenator of FIG. 2 can be constructed with the three cylinders concentrically disposed about the same longitudinal axis which can correspond to drive shaft 44. In this case, the inner two cylinders would, like outer cylinder 39, fit into suitable slots cut in the inner face of the spiders. Also, the innermost cylinder could be of solid construction. By avoiding completely any contact between the cylinders, a more gentle form of oxygenation and higher rotational rate may be achieved without foaming. The solid construction of the inner cylinder, of course, diminishes the priming volume.

The advantage of using a bellows-type engine, such as the simplified version illustrated in FIG. 1, to drive the camshaft, is found in the fact that this construction presents no gas sealing problems. However, there is a tendency for the bellows to squirm and introduce slight irregularities in the operation of the oxygenator. If desired, this engine can be replaced with a conventional piston-type engine wherein the oxygen is led to and from the cylinder head via a flexible plastic tube. In one practical embodiment of such an engine, the cylinder was made of brass, the piston of carbon, and sealed ball bearings of stainless steel construction were employed. It would be noted in connection with the operation of the engine portion of the system that a higher engine speed adds greatly to the stability of the apparatus and that the engine preferably should run at several times the frequency of the various pumps. This relationship can be, of course, obtained by incorporating suitable gearshift provisions in the drive mechanism.

It has been found in the operation of the apparatus of FIG. 1 that the tubing 54 connected to the bottom of the reservoir should be of fairly large diameter, approximately two inches, so that any oxygen bubbles entrapped in the blood when the blood level is below the bottom of the reservoir can be released readily by coming to the surface. Such a tube dimension has the effect of increasing the volume of blood needed in the operation of the system. However, reservoir 5 can be eliminated from the system with a gravity flow of blood directly from the oxygenator to pressure pump 6.

In FIG. 3 there is schematically depicted a modification of the internal portion of the oxygenator of FIG. 1. In this alternative construction, a single, rotating cylinder 82, the counterpart of element 39, is covered with a stocking 83 made of loosely woven, plastic material. This stocking, which preferably should be about three-quarters of an inch thick, performs much like a screen except that the weave is loose enough so that each fiber is individually coated with blood as the stocking dips into the blood pool. Thus, while each fiber is wetted by the blood, the blood cannot bridge across adjacent fibers so as to form, in effect, a single large blood clot around cylinder 82.

A flow-through pressure pump which can replace the apparatus of FIG. 4 in the oxygenating system is illustrated in FIG. 5. In this alternative construction, a cylinder 85 having an inwardly projecting, rounded collar 86 adjacent each end thereof encloses a tubular element 87, preferably made of plastic or silicone rubber. This tubular element, which is closed off at each end by a stopper 88 provided with a central bore 89, is held under tension with portions adjacent each end thereof pinched between confronting surfaces of stopper 88 and collar 86. Oxygenated blood is fed into one side of the pump and pressurized oxygen is fed into the interior of the pump via an entrance port 90 cut in the wall of cylinder 85 at a point intermediate its length. Each pumping stroke occurs, of course, when an oxygen pressure pump collapses tubular element 87 and forces the blood out of the exit side of the pump.

Some of the characteristics of the embodiment of FIG 5 which recommend its employment include the unidirectional flow of blood, the simple form of the tubular pumping member and the ability of this member to withstand numerous sterilizations. The arrangement of FIG. 5 can be slightly modified by utilizing a tubular pumping element sealed at one end thereof in place of the open-ended element 87. With such a design, cylinder 85 would also be closed at a corresponding end thereof. Such a construction eliminates the need of the second stopper and minimizes any possible oxygen leakage from the pump. However, the cleansing operation is complicated because of the difficulty in turning such a closed tubular member inside out.

In FIG. 6 there is illustrated one arrangement for detachably connecting the oxygenator 4 as a unit to the oxygen-driven engine. Here, engine 2 and all of its conventional components, including, for example, the piston, cylinder and crankshaft, as well as camshaft 24 and ball valve assembly 3, are all accommodated within the rectangular engine block 91. End plate 38 of the oxygenator is secured by a pair of screws 92, only one of which is shown, to that face of the block through which the drive shaft of the engine projects. A circular flange 93 and a tubular arm 94 extend from the left-hand side of this end plate as viewed in this figure. The other end plate 37 has a similar but somewhat wider circular flange 103 projecting therefrom which has a blood collecting well portion 95 formed along the bottom part thereof. Secured to the other side of end plate 37 is a sleeve 96.

The outer glass, stationary cylinder 36 of the oxygenator fits closely within flanges 93 and 103, extending sufficiently far enough under these flanges to prevent any blood leakage from the central portion of the oxygenator. This cylinder is further sealed in place during the operation of the oxygenator by strips of pressure-sensitive plastic tape 97 which adhere to adjacent portions of the outer surface of this cylinder and the edges of the flanges. The oxygenator unit is held together by an L-shaped member 98 which consists of a tubular arm 99, whose diameter is slightly larger than that of arm 94 extending from end plate 38, and a second arm 100 at right angles thereto which is designed to slidably fit within sleeve 96. Locking screw 101, which passes through aligned apertures in arms 99 and 94 when they are in the telescopic position shown, and set screw 102 of sleeve 96, maintain the assembly together. The oxygenator unit, it will thus be seen, can be detached as a unit from the engine by means of screws 92, and the oxygenator itself can be disassembled for cleaning and inspection purposes by first loosening screw 101, then set screw 102, and then unwrapping the plastic tapes 97. By the same token, it will be appreciated that the oxygenator unit, after it has been inspected and cleaned, can be reassembled and stored in a sterile condition until it is next needed.

A modification of the present invention wherein the competence of flow-through pressure pump 6, which sends oxygenated blood to the surge chamber 8 and thence to the patient, is automatically controlled by the level of the blood within the oxygenator, is generally illustrated in FIG. 7. To achieve this type of control, oxygen-driven engine 2, with oxygenator 4, pump 6 and surge chamber 8, not shown, attached thereto, is positioned on the tips of a pair of screws 112, only one of which is shown, which extend through a stationary platform 106 secured to the upright post of a stand 104. The purpose of supporting the complete assembly on only these two points is to permit the axis of the oxygenator to tilt with respect to the horizontal in response to the amount of blood within it. This movement is utilized to control the rate of pumping. The mass of oxygenator 4 plus that of appended pressure pump 6 and surge chamber 8, which, although not shown, is disposed side by side with this pump, is more than enough to overbalance the engine block 91 on the two-point suspension provided by screws 112. But the system can be brought to an even attitude by adjusting screw 114 which regulates the tension of spring 113 and the downward force acting on the engine block on the other side of the point supports.

With pressure pump 6 suspended below the oxygenator, oxygenated blood can flow directly from well 95, down through supporting tube 117 and via the one-way flapper valve 118 into the central portion of the pump. The oxygen for operating this pump, as shown in FIG. 5, is supplied to the annular space between rubber tube 87 and metallic housing 85 by flexible tube 116. This oxygen, as mentioned hereinbefore, comes from the engine exhaust, and it first passes through a one-way flapper valve, similar to 118, before it enters this branch line. The operation of pump 6 is controlled by throttling its exhaust. To accomplish this, line 116 is also connected via an internal passageway in engine block 91, not shown, to a horizontal tube 109 that extends to the right, as viewed in this figure, from the lower edge of the engine block. Tube 109, which is the exhaust line for pump 6, terminates at its outer end in a valve assembly 110 whose closure member is ball 111. It will be readily appreciated that when ball 111 rests on its seat, closing valve 110, oxygen cannot be exhausted from pump 6 since there is no other exit from this pump due to the blocking action of the check valve previously mentioned. Tubular member 87, therefore, must remain in a compressed condition and, consequently, the pump cannot prepare itself for a second stroke.

The apparatus for controlling valve 110 consists merely of a horizontal arm 107 that extends from fixed platform 106 in a direction parallel to tube 109. This arm carries an adjustable screw 108 at a position immediately below the center of the seat of valve 110, and the end of this screw is designed so it can pass into this valve and contact ball 111. Horizontal arm 107 also carries a strap 115 which loops over tube 109 so as to limit the counterclockwise rotation of the apparatus about point supports 112.

When the apparatus is first put in operation, that is, with little or no blood in the oxygenator, spring 113 counteracts the overbalancing action of the oxygenator plus its appended equipment, and the apparatus assumes a generally horizontal attitude. Pressure pump 6 is incapacitated at this time because its exhaust line is completely closed, with ball 111 resting on its seat and completely out of contact with the tip of screw 108. As the blood level rises in the oxygenator, the increased weight thereof contributes to the mass of the apparatus on the right of the supporting points, as viewed in FIG. 7; the above balance is disturbed and the oxygenator and the engine block commence to rotate in a clockwise direction about the pivot points. Since exhaust pipe 109 is attached to the engine block, it, too, takes part in this rotation. As more and more blood flows into the oxygenator, the angular displacement of the above apparatus increases until a point is reached at which pipe 109 is tilted sufficiently far to bring the top part of screw 108 into contact with ball 111. The amount of blood at this point is now close to the level considered safe for operation of the system. Any further flow of blood now results in valve 110 being cracked by the upward movement of ball 111 off of its seat, and the pump commences to operate at a relatively low rate. This rate increases with further opening of valve 110 until the exhaust line is completely opened.

If the level of the blood in the oxygenator decreases at any time below the safe level so that there is the danger of oxygen gas being sucked into the pump, the oxygenator rotates in a counterclockwise direction, contact is broken between ball 111 and screw 108, and pump 6 is stopped. In actual operation, the oxygenator assumes a position in which the ball valve is continuously tickled by pressure of the screw, and the pump operates with partial capacity to maintain the blood level fairly constant. It would be pointed out that the blood leaves pump 6 via a one-way flapper valve 119 and then proceeds to the surge chamber 8 which has a general appearance similar to that of pump 6 as illustrated in FIG. 5. This surge chamber, as mentioned hereinbefore, is positioned alongside pump 6 and also suspended from oxygenator 4. It would be pointed out that in the operation of the above system the apparatus is first charged with a sterile saline solution and then with blood.

Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. For use in a system that assumes the functions of the lungs of a patient during surgery, the combination of a cylindrical container, said container adapted to contain a pool of blood being positioned in a substantially horizontal attitude, means for forming a pool of blood at the bottom of said container thereof, a first sleeve mounted between opposite end walls of said container, means for rotating said sleeve about an axis that is parallel to but below the longitudinal axis of symmetry of said container, the location of said axes with respect to the surface of said pool of blood being such that a wall length portion of said sleeve extends into said blood pool whereby the inner and outer wall surfaces of said sleeve become covered with a thin film of blood after a few rotations of said sleeve, a second sleeve positioned within said first sleeve, a loop of wire secured around the outer surface of said second sleeve adjacent each end thereof, said loops of wire freely resting on a portion of the inner wall surface of said first sleeve whereby a finite separation between the lower inner wall surface of said first sleeve and a confronting portion of the outer wall surface of said second sleeve is established and whereby said second sleeve rotates in response to the rotation of said first sleeve, means for establishing a continuously fresh oxygen atmosphere within said enclosed container and means for withdrawing blood from said pool.

2. In an oxygenating system, the combination of an enclosed cylindrical container adapted to contain a pool of blood, means for accumulating said pool of blood at the bottom of said container, a holler cylinder mounted within said container with a wall length portion thereof adapted to extend into said pool of blood, a source of compressed oxygen, means responsive to the expansion of a stream of oxygen released from said source for imparting rotary motion to said hollow cylinder whereby the inner and outer wall surfaces thereof become coated with a thin film of blood after a few rotations of said cylinder and means for directing the released oxygen after its expansion into said container thereby to oxygenate the blood forming said thin films.

3. In a system for temporarily assuming the functions of a patient's heart and lungs during surgery, the combination of a blood oxygenator adapted to contain a pool of blood, said oxygenator including as a component thereof a hollow cylinder adapted to rotate partially within said pool of blood, an engine rotating said cylinder, a suction pump for collecting blood seeping into the operating area and adding this blood to said blood pool, a pressure pump, said pressure pump being connected to said oxygenator and adapted to be connected to the arterial system of said patent, a source of compressed oxygen, said vacuum pump, said engine and said pressure pump being operated by the expansion of compressed oxygen from said source, said oxygen after its expansion serving to oxygenate the blood within said oxygenator.

4. In a system for temporarily assuming the heart and lung actions of a patient during surgery, the combination of a blood oxygenator, adapted to contain a pool of blood, said oxygenator including a sleeve, means for dispersing the blood which is to be oxygenated in a thin film over the inner and outer wall surfaces of said sleeve, means for rotating said sleeve partially within a blood pool, a pressure pump connected to said oxygenator and adapted to be connected to said patient for pumping blood from said oxygenator into the arterial system of the patient, a source of compressed oxygen, said means for rotating said sleeve and said pump being operated by the expansion of compressed oxygen from said source, said oxygen after its expansion serving to oxygenate the blood films on the inner and outer wall surfaces of said sleeve.

5. In an arrangement as defined in claim 4, a suction pump, said suction pump adopted to remove blood collecting in the operating area and adopted to add this blood to the blood pool within said oxygenator, said pump also being operated by the expansion of compressed oxygen from said source.

6. In an arrangement as defined in claim 5, means for directing the blood from said pressure pump against a cushioning member whereby the flow of said blood is smoothened prior to its introduction into the arterial system of the patient.

7. For use in a system for temporarily assuming the functions of a patient's lungs, the combination of a blood oxygenator adapted to contain a pool of blood, said oxygenator including a blood dispersing member adapted to rotate partially within said blood pool, means for enclosing said dispersing member in an oxygen atmosphere, a source of compressed oxygen, an engine for rotating said dispersing member, said engine being operated by the expansion of compressed oxygen supplied from said source within a compartment thereof, said oxygen after its expansion being coupled to said means for enclosing said dispersing member, thereby to provide said oxygen atmosphere.

8. In an arrangement as defined in claim 7, a pressure pump connected to said oxygenator, said pressure pump when connected to said patient forcing blood withdrawn from said pool into the arterial system of said patient, said pump operating by the expansion of compressed oxygen, and means for cutting off the flow of blood to said pump when the blood level of said pool falls below a predetermined value.

9. A blood oxygenating system for a patient undergoing surgery, comprising a blood oxygenator, a blood supply line for feeding blood into said oxygenator, means for collecting blood seeping into the operating area and for adding this blood to said blood supply line thereby to augment the blood available in the oxygenator, said last-mentioned means including a source of compressed oxygen, a suction pump, said suction pump being operated by the expansion of compressed oxygen fed thereto from said source, and means for coupling said suction pump to said oxygenator whereby the oxygen employed to operate said suction pump is subsequently vented into said oxygenator.

10. In a system for oxygenating the blood of a patient undergoing surgery, the combination of a blood oxygenator adapted to contain a pool of blood, a supply line adapted to connect the venous system of said patient to said blood oxygenator whereby blood flows by gravity from said patient into said oxygenator, a syphon, said syphon collecting blood seeping into the operating area and feeding it into said supply line thereby to increase the blood within said oxygenator, a suction pump connected to said syphon for starting said syphon, said suction pump being operated by the expansion of compressed oxygen within a compartment thereof, and means for coupling the oxygen vented from said compartment between successive strokes of said suction pump into said oxygenator thereby to oxygenate the blood therein.

11. In an oxygenator system, the combination of a blood oxygenator, a first blood supply line having one end connected to said oxygenator and the other end adapted to be connected to the venous system of a patient, said patient being elevated above the level of said oxy-

genator whereby blood flows by gravity from said venous system into said oxygenator, an enclosed chamber, a suction pump, the suction line thereof being connected to an opening in the top wall of said chamber, tubing connected between the bottom of said chamber and said first blood supply line, a second blood supply line, one end of said second blood supply line terminating in an aperture cut in one wall of said chamber and the other end adapted to terminate in the operating area whereby blood seeping into said area is sucked into said chamber by the vacuum developed therein by said suction pump, said storage chamber being located in a position above said first blood supply line whereby blood flows from said chamber by gravity into said first blood supply line through said tubing and thereafter continues to flow by syphoning action until substantially all of the blood is removed from the operating area.

12. In an arrangement as defined in claim 11 wherein said suction pump is operated by the expansion of a compressed gas within a chamber thereof, a source of compressed oxygen, and means for periodically coupling compressed oxygen from said source to said compartment for operating said suction pump, and means for periodically venting oxygen from said compartment into said oxygenator.

13. Apparatus for use in oxygenating blood comprising, in combination, a tubular container closed at each end thereof, a first hollow cylinder mounted between opposite ends of said tubular container and adapted to rotate about a horizontal axis, a second hollow cylinder positioned within said first hollow cylinder, said second hollow cylinder being supported by said first hollow cylinder at only two spaced locations adjacent each end of said first hollow cylinder such that a finite separation exists between the confronting lower wall surface portions of said first and second hollow cylinders, a blood inlet and outlet in the lower wall portion of said tubular container, an adjacent gas inlet and outlet in the top wall portion of said tubular container, said inlets being adjacent one end of said container and said outlets being adjacent the other end of said container, means for rotating said first cylinder whereby said second cylinder tends to rotate therewith, said means including a gas-operated engine, said engine being of the type wherein the motive force is derived from the expansion of a compressed gas within a compartment of said engine, means for coupling compressed oxygen to said engine and means for coupling said oxygen after its expansion to said gas inlet in the top wall portion of said tubular container.

14. Apparatus for use in oxygenating blood comprising, in combination, a tubular container closed at each end thereof, a first hollow cylinder mounted between opposite ends of said tubular container and adapted to rotate about a horizontal axis, a second hollow cylinder positioned within said first hollow cylinder, said second hollow cylinder being supported by said first hollow cylinder at only two spaced peripheral locations adjacent the ends of said first hollow cylinder such that a finite separation exists between the confronting lower wall surface portions of said first and second hollow cylinders, a blood inlet and outlet in the lower wall portion of said tubular container, a gas inlet and outlet in the top wall portion of said tubular container, said inlets being adjacent one end of said container and said outlets being adjacent said other ends of said container, means for rotating said first hollow cylinder, said means including an engine, said engine being of the type wherein the motive force is derived from the expansion of a compressed fluid within a compartment thereof, a source of pressurized oxygen, means for periodically feeding pressurized oxygen from said source to said compartment, thereby to operate said engine, and means for coupling said oxygen after its expansion in said compartment to the gas inlet in said top wall portion of said tubular container.

15. In an arrangement as defined in claim 13, a pressure pump, said pump being of the type wherein the pumping force is developed by the expansion of a compressed fluid, means for connecting the blood outlet of said oxygenator to the input of said pump, the output of said pump being adapted to be coupled to the arterial system of the patient, and means for connecting a pulsating stream of oxygen derived from said source of pressurized oxygen to said pump.

16. For use in a blood oxygenating system for a patient undergoing surgery the combination of a blood oxygenator, a first blood supply line, one end of said line being adapted to connect the patient's venous system to said oxygenator, a suction pump, a blood storage chamber, means for coupling the suction side of said pump to the top of said storage chamber, means for connecting the bottom of said storage chamber to the other end of said first blood supply line, a second blood supply line, one end of said second line being connected to an opening in one wall of said storage chamber and the other end of said line adapted to terminate in the operating area whereby said suction pump during its operation creates a vacuum within said storage chamber to draw blood seeping into said operating area into said storage chamber, the blood in said storage chamber thereafter flowing by gravity into said supply line, an enclosed container, a liquid within said container, means connecting the suction side of said pump to an aperture cut in the top wall of said container, a length of tubing, said tubing extending through an aperture cut in the top wall of said container and into said fluid for a predetermined distance whereby air is drawn through said tubing and through said liquid into said suction line when the degree of vacuum within said chamber exceeds a predetermined amount, said suction pump being operated by the expansion of compressed oxygen within a compartment thereof, means for periodically coupling compressed oxygen to said compartment and means for subsequently venting oxygen after its expansion in said compartment into said oxygenator.

References Cited by the Examiner

UNITED STATES PATENTS

2,286,480	6/42	Farr	261—92
2,693,802	11/54	Osborn	128—214
2,702,035	2/55	Gibbon et al.	128—214
2,812,716	11/57	Gray	128—214
2,927,582	3/60	Berkman et al.	128—214
3,026,871	3/62	Thomas	128—214
3,037,504	6/62	Everett	128—214

FOREIGN PATENTS

461,160	1/51	Italy.

OTHER REFERENCES

Karlson et al.: "Pump-Oxygenator to Supplant the Heart and Lungs for Brief Periods," from Surgery, vol. 29, No. 5, May 1951, pp. 678–696.

Winterscheid et al.: "A Coronary Sinus System for Use During Cardiopulmonary Bypass," from Surgery, vol. 48, No. 4, October 1960, pp. 785–795.

Crafoord et al.: "Clinical Studies in Extra-Corporeal Circulation with a Heart-Lung Machine," from Acta Cherurgica Scandinavica, vol. 112, No. 34, pp. 220–225.

RICHARD A. GAUDET, *Primary Examiner.*

RICHARD J. HOFFMAN, *Examiner.*