Oct. 25, 1955

D. G. MELROSE

2,721,732

APPARATUS FOR MIXING LIQUIDS AND GASES

Filed Dec. 23, 1952

2 Sheets-Sheet 1

FIG. 1.

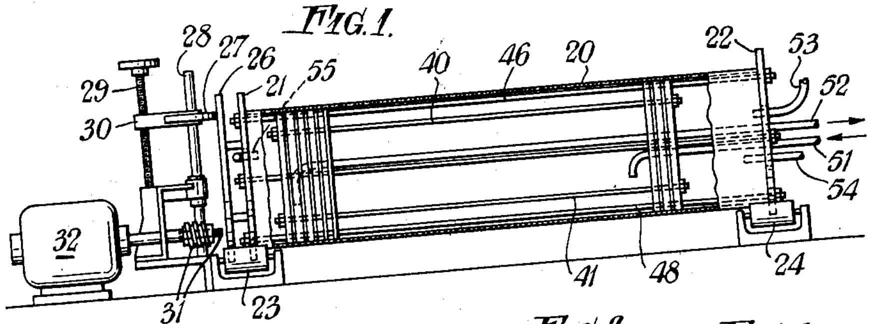

FIG. 2.

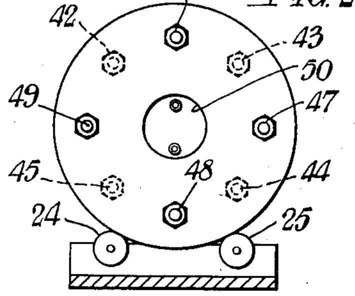

FIG. 3.

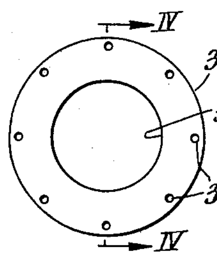

FIG. 4.

FIG. 5.

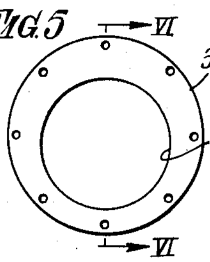

FIG. 6.

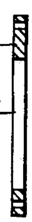

FIG. 7.

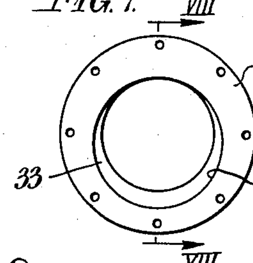

FIG. 8.

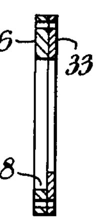

FIG. 10.

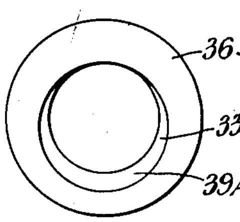

FIG. 9.

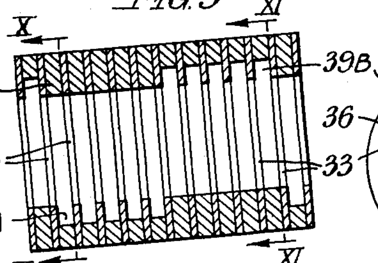

FIG. 11.

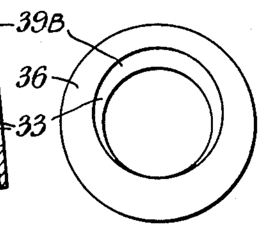

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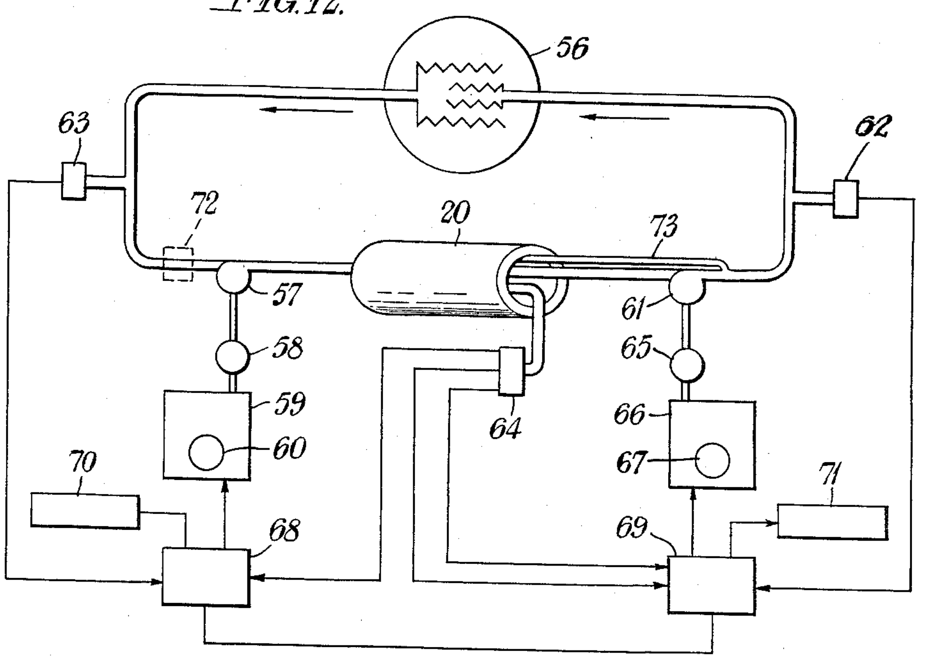
FIG. 12.



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APPARATUS FOR MIXING LIQUIDS AND GASES

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Application December 23, 1952, Serial No. 327,527

Claims priority, application Great Britain January 3, 1952

6 Claims. (Cl. 261—83)

The present invention relates to improved apparatus for quickly bringing a gas into intimate contact with a liquid and, although not exclusively limited thereto, is particularly suitable for oxygenating blood.

In order to carry out an examination of, or surgical operation upon, a patient's heart in substantially bloodless conditions, it has already been proposed to by-pass the heart and lungs by taking blood from the patient on the venous side and returning it on the arterial side, placing in the by-pass apparatus which re-oxygenates the blood and returns it at an appropriate rate through the remainder of the body.

A known way of re-oxygenating blood is to spread out the blood into a thin film and then flow oxygen over the film, but in the past several difficulties have been experienced in carrying out such operations, among which may be mentioned that of providing an adequate rate of flow of oxygenated blood whilst avoiding undue foaming, haemolysis or other deleterious effect upon the blood, and of accurately controlling the rate of flow of the blood to the needs of the patient.

It is an object of the present invention to provide apparatus which in these and several other respects is an improvement on that known hitherto.

A preferred form of the invention will now be described with reference to the accompanying diagrammatic drawings in which:

Figure 1 is a side elevation of a blood oxygenator,

Figure 2 is a right-hand end elevation, on a somewhat larger scale, of the same apparatus,

Figure 3 is a side elevation of one of several rings forming part of the oxygenator.

Figure 4 is a section on the line IV—IV of Figure 3,

Figure 5 is a side elevation of one of several annuli making up the oxygenator,

Figure 6 is a section on the line VI—VI of Figure 5,

Figure 7 is an elevation showing one ring and one annulus placed in face-to-face contact,

Figure 8 is a section on the line VIII—VIII of Figure 7,

Figure 9 is a sectional elevation, on an enlarged scale, through a portion of the oxygenator shown in Figure 1,

Figure 10 is a section on the line X—X of Figure 9,

Figure 11 is a section on the line XI—XI of Figure 10, and

Figure 12 is a circuit diagram illustrating apparatus for controlling the oxygenator of Figure 1.

The apparatus illustrated in Figures 1 to 11 comprises a transparent cylindrical shell **20** which is 30 inches long and of internal diameter 8 inches. It is made of a material which may be readily sterilised, such as compressed nylon. At its two ends it is closed by centrally apertured plates **21** and **22** each of external diameter 10 inches. The end-plates are mounted for rotation upon two pairs of rollers, such as those shown at **23**, **24** and **25**, with the axis of the cylindrical shell inclined to the horizontal at a small angle which may be 5° for example.

Fixed on the left-hand end plate **21**, and spaced from it, is a parallel driving plate **26** forming part of a continuously variable friction gear the other wheel **27** of which can be moved up and down a rod **28** with the aid of a manually operable screw **29** threaded through a yoke **30** which carries the friction wheel **27**. The friction wheel **27** is splined on the rod **28** and is rotated, through worm gear **31** at the lower end of the rod, by a fractional H. P. electric motor **32**. The motor may be, for example, of 1/30 H. P. running at 960 R. P. M. and the speed of rotation of the cylindrical shell may be varied to anything between about 24 to 120 R. P. M. by moving the friction wheel **27** radially with respect to the driving plate **26**.

Fixedly secured within the cylindrical shell **20** are a plurality of ring-shaped plates, also made of nylon, and arranged so that their apertures constitute a passage from end to end of the cylindrical shell. The plates are of two somewhat similar kinds and the two kinds are arranged alternately throughout the length of the cylinder. Henceforth the two kinds will be called "rings" (of which there may be 77) and "annuli" (of which there may be 76) in order to distinguish them one from the other.

A ring is shown in detail at **33** in Figures 3 and 4. It is circular and of external diameter such that it is a sliding fit in the cylindrical shell **20**. It is formed with a central aperture **34** of 4⅜ inches diameter and is 1/24 inch thick. It is also formed with eight equi-angularly disposed holes such as those shown at **35**.

Each annulus **36** (Figures 5 and 6) is similar in shape to a ring except that it is 1/16 inch thick and is formed with a circular aperture **37** of 5⅜ inches diameter, the centre of which is eccentric by 1 inch.

As stated above these rings and annuli are arranged alternately in the cylindrical shell **20** and Figures 7 and 8 illustrate one of each as they are arranged in the cylindrical shell, the annulus being in front of the ring in Figure 7. It will be seen that when so placed together they form a crescent-shaped rabbet **38** which, when another ring is added to the other side of the annulus, is converted into a crescent-shaped trough of the kind shown at **39A** or **39B** in Figure 9.

The rings and annuli are also arranged in groups of two kinds which alternate along the length of the cylindrical shell **20**. One group consists of five rings and five annuli having the maximum depth of the crescent-shaped troughs **39A** arranged at 6 o'clock in end view, as shown in Figure 10. The other group consists of five rings and five annuli arranged with the maximum depth of the troughs (**39B** in Figure 9) all arranged at 12 o'clock in end view, as shown in Figure 11.

The rings and annuli are assembled in this manner upon four chromium plated steel rods such as those shown at **40** and **41** in Figure 1 and are tightened together with the aid of four nuts (**42**, **43**, **44** and **45** in Figure 2) so as to be liquid tight. They are then fitted into the cylindrical shell **20** (after the end-plate **22** has been removed) upon four other chromium plated steel rods **46**, **47**, **48** and **49**, whereupon the end-plate **22** is assembled on these four rods and tightened on to the end of the cylindrical shell with the aid of suitable nuts.

The end-plate **22** is formed with an aperture **50** through which are passed an inlet pipe **51**, for blood, dipping into the rear or upper end of the oxygenator, an outlet pipe **52**, also for blood, dipping into the forward end of the oxygenator, an outlet pipe **53** for oxygen and a pipe **54** with the aid of which the depth of blood in the oxygenator may be measured.

The left-hand end plate **21** is also formed with an aperture through which is passed a pipe **55** serving to suply oxygen to the oxygenator.

It will be seen that the cylindrical shell, rings, annuli and pipes are all completely detachable for cleaning.

The cylindrical shell, rings and annuli thus together constitute a kind of elongated cylinder-like shell or hollow body, the general axis of which is inclined to the horizontal and through which cylinder-like shell the blood may be flowed downwardly under gravity while oxygen is passed in contra flow over the surface of the blood.

In effect the internal shape of the cylindrical shell 20 has been altered, by the addition of the rings and annuli, and the container has been converted to an elongated cylinder-like shell or hollow body, the outer surface of which is cylindrical but the internal surface of which is in the form of a plurality of end-to-end cylinder-like assemblies all having their axes eccentric with respect to a predetermined axis, namely the axis of the external cylindrical surface of the shell. Furthermore, the axis of one cylinder-like assembly is displaced by 180° with respect to each of the two assemblies adjacent to it and with reference to the predetermined axis.

The apparatus so far described is used in the following way:

The motor 32 is set running so as to drive the friction wheels 27 and 26 which in turn rotate the oxygenator at a convenient speed of say 50 R. P. M. Venous blood is introduced into the oxygenator, by way of the inlet 51, at a rate which is controlled in a manner to be described later, and flows by gravity, and relatively slowly, to the left-hand end of the oxygenator whence it is pumped out, at the same rate as it enters, through the outlet pipe 52. Simultaneously a stream of oxygen is passed continuously through the oxygenator by way of the pipes 55 and 53, in the opposite direction to the flow of blood.

Consider an instant at which blood drops into the oxygenator when a group of five crescent-shaped troughs 39B are immediately above the end of the inlet pipe 51, i. e. are in the 12 o'clock position shown in Figure 11 and at the right-hand end of Figure 9. Then the incoming blood falls on to what is approximately a cylindrical surface and tends to flow by gravity towards the adjacent group of crescent-shaped troughs 37A which are in the 6 o'clock position as shown in Figure 10 and at the left-hand end of Figure 9. In fact, however, before the blood can pass from one group to the next the oxygenator has made several revolutions. Nevertheless the tendency is always for the blood to flow from right to left through the oxygenator. Each time the blood rests in a group of 6 o'clock troughs 39A, the two sides of each thin ring 33, and the floors of the troughs between these rings, become coated with blood and a thin film is carried up to the 12 o'clock position and down again as the oxygenator rotates. In this way a thin film of blood is maintained in contact with the oxygen at a capacity which, when the oxygenator is rotated at its maximum speed, gives a minute area of 120 square metres.

Some of the blood is continually being spread into a film in this way, carried up in to the stream of oxygen, and then returned to a pool lying in a 6 o'clock set of crescent-shaped troughs. At the same time each little pool remaining in the 6 o'clock position is alternately raised to lie on a cylindrical surface shown at the right-hand end of Figure 9 and is then lowered into a trough, the blood flowing down through the oxygenator simultaneously with this continuous cycling of the blood into films and back into a pool. In effect therefore the several pools in a group are alternately formed and emptied in alternating sequence, and the fact that adjacent groups are displaced angularly by 180° ensures that as pools are formed in one group they are being emptied in an adjacent group.

The present invention possesses several advantages as compared with known apparatus for achieving the same end, not the least of which is that it avoids the use of plates having edges which cut through the blood at high speed, in a direction transverse to the edges, and in this way damage the blood. It will be seen that, in the present apparatus, the edges of the rings are the only ones which move through the blood and each edge moves not only at a relatively low speed, but also in a direction approximately parallel with itself, thus avoiding damage to the blood.

Furthermore, less blood (approximately 50% less) is required to fill the oxygenator to working level, better mixing of the blood is achieved, the whole of the available film-forming surface of the apparatus is brought into use irrespective of the volume of blood passing through in unit time, and the capacity of the machine is greater.

Apparatus for controlling the rate of flow of blood through the oxygenator is shown in Figure 12.

The patient is represented at 56, the venous and arterial sides being at the left and right-hand respectively.

Blood is drawn from the venous side of the patient by a pump 57 driven by a motor 58 under the control of a controller 59 which is both manually and automatically operable and which supplies power to the motor 58 independently of the mains voltage. The rate of supply can be determined either by a manual setting 60 or by electric signals generated in a manner to be described.

The pump 57 passes the blood from the patient into the oxygenator which may be identical with that illustrated in Figures 1 to 11.

Re-oxygenated blood is extracted from the oxygenator, and returned to the patient on the arterial side, by a pump 61 the pressure of which is recorded by an electromagnetic manometer 62, whilst a similar manometer 63 records the suction produced by the pump 57.

A level recorder 64 gives a continuous record of the level of blood in the oxygenator and also provides signals when the level rises or falls to danger limits.

The pump 61 is driven by a motor 65 under the control of a controller 66 similar to 59 and having a manual setting 67.

Mixers 68 and 69 are electronic valve-operated units which combine the signals from the manometers and deliver master signals to the electronic controllers 59 and 66 and also to alarm devices 70 and 71 which include steady green and winking red lamps together with buzzers, as desired, to provide visible and/or audible warning of any dangerous condition, approaching or present.

The rate at which blood is supplied to and withdrawn from the patient, i. e. the rate at which it passes through the oxygenator, normally should remain constant and a large part of the function of the control apparatus is to ensure this.

An example of the way in which this control apparatus is used is as follows:

Suppose the output of the pump 57 falls, the controller 59 is such as to boost it up. If, however, the boosting is still insufficient, an alarm is provided at 70, in which case any one of a variety of expedients may be adopted. For example, the mixer 68 may operate on 69 so as to reduce the output of pump 61, via controller 66 and motor 65, until the blood rates at opposite ends of the oxygenator are again equalized. As an alternative the control apparatus may be operated manually until the desired functioning is arrived at, whereupon it may be re-set to operate automaticaly.

Generally, the control apparatus should be of the greatest flexibility so that, in order to compensate for a change in any one of these factors, any or all of the others may be adjusted either automatically or manually.

If desired a by-pass circuit 73 may be provided with the aid of which saline may be continuously circulated through the oxygenator, and air bubbles in the various pipes opened to the atmosphere and thus excluded from the arterial side of the apparatus.

A reservoir may be located at any convenient position, such as at 72, from which reservoir blood may be taken to replenish the circuit.

What I claim is:

1. Apparatus for bringing a liquid and gas into intimate contact, including an elongate hollow body member, means for supporting said member so that it is inclined to the horizontal, means for rotating said member about a central axis, inlets and outlets to said member such that a liquid may be flowed through it under gravity and a gas may be passed through it above the liquid, the internal shape of said member being in the form of a plurality of groups of annuli having inner cylindrical surfaces the axes of which are eccentric with respect to said central axis, the axis of said groups of annuli being displaced 180° with respect to that of each adjacent group of annuli with reference to said central axis, and a plurality of spaced rings, each formed with an aperture coaxial with said central axis, arranged at spaced intervals throughout the length of said groups of annuli so as to subdivide said groups.

2. Apparatus for bringing a liquid and gas into intimate contact, including a hollow elongate cylinder-like shell, means for supporting said shell so that it is inclined to the horizontal, means for rotating said shell about a central axis, inlets and outlets to said shell such that a liquid may be flowed through it under gravity and a gas may be passed through it above the liquid, the internal shape of said shell being in the form of a plurality of sets of alternately arranged crescent-shaped troughs, those of one set being arranged with the maximum depth of trough angularly displaced with respect to the maximum depth of an adjacent set.

3. Apparatus as claimed in claim 2, wherein the angular displacement between the maxima is 180°.

4. Apparatus for bringing a liquid and gas into intimate contact, including a hollow elongate cylinder-like shell, means for supporting said shell so that it is inclined to the horizontal, means for rotating said shell about an axis, inlets and outlets to said shell such that a liquid may be flowed through it under gravity and a gas may be passed through it above the liquid, the internal shape of said shell being in the form of a plurality of sets of alternately arranged annuli, the inner cylindrical surfaces of which are eccentric with respect to said axis, the eccentricity of one set being angularly displaced with respect to those of another set, and a plurality of rings each formed with an aperture coaxial with said axis and arranged at spaced intervals throughout the length of said shell.

5. Apparatus for bringing a liquid and gas into intimate contact, including a cylinder-like shell having its axis inclined to the horizontal, means for rotating said shell about its axis, inlets and outlets to said shell such that, while it is rotating, a liquid may be flowed through it under gravity and a gas may be passed through it above the liquid, a plurality of centrally apertured rings and a plurality of eccentrically apertured annuli stacked within said shell, the annuli being arranged in sequentially arranged groups the eccentricities of successive groups being displaced angularly and a ring being located between each adjacent pair of annuli.

6. Apparatus as claimed in claim 5, including two groups of annuli the angular displacement between adjacent ones of which is 180°.

References Cited in the file of this patent

UNITED STATES PATENTS

1,253,401	Lorimer	Jan. 15, 1918
1,592,231	Stroder	July 13, 1926
2,575,688	Smith	Nov. 20, 1951

FOREIGN PATENTS

138,694	Germany	Feb. 12, 1903
348,244	Great Britain	May 14, 1931