June 29, 1965 H. F. EVERETT 3,191,600

BLOOD SUCTION APPARATUS

Filed May 4, 1962 3 Sheets-Sheet 1

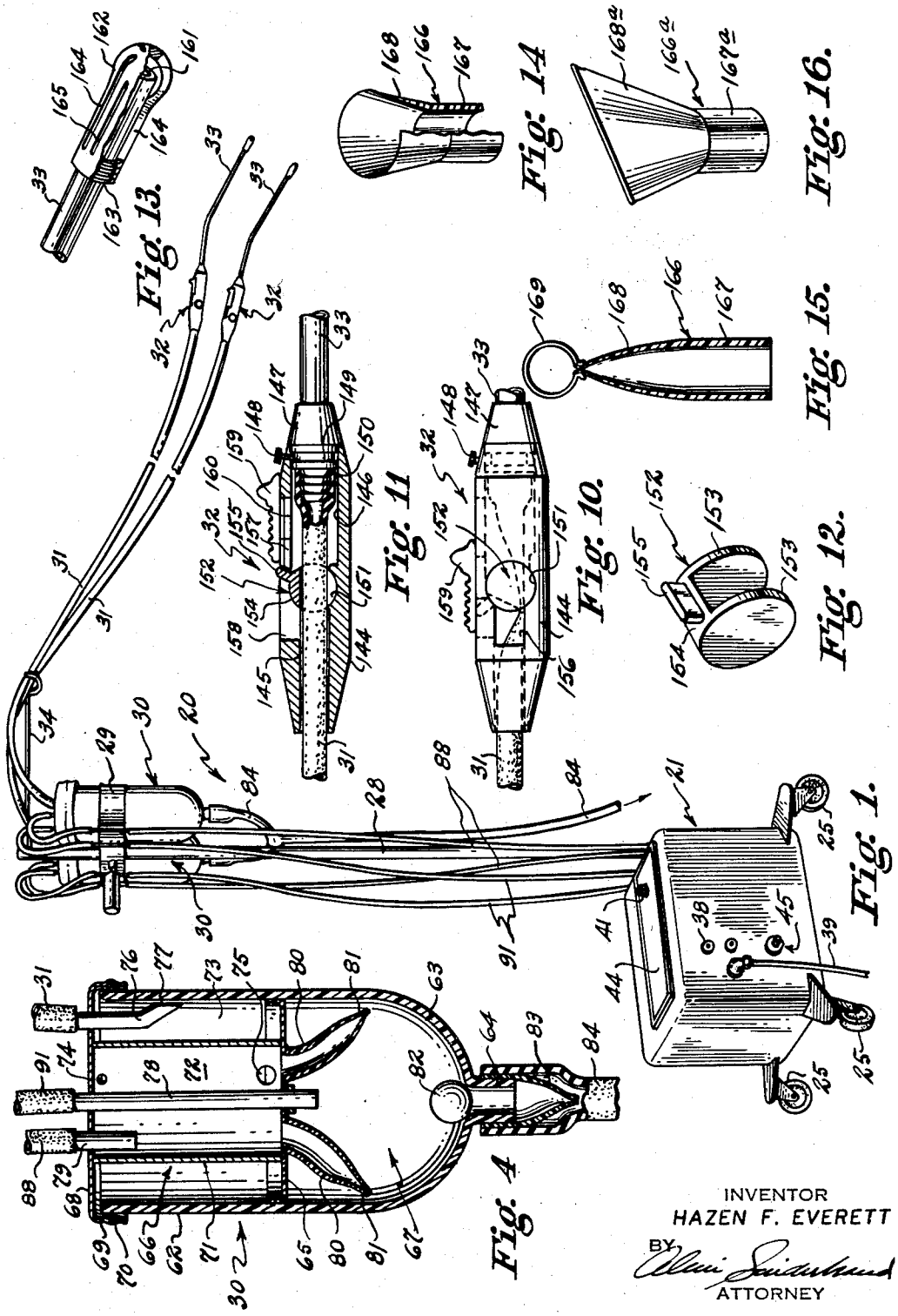

Fig. 1.

Fig. 4

Fig. 10.

Fig. 11

Fig. 12.

Fig. 13.

Fig. 14

Fig. 15.

Fig. 16.

INVENTOR
HAZEN F. EVERETT
BY
ATTORNEY

June 29, 1965 H. F. EVERETT 3,191,600

BLOOD SUCTION APPARATUS

Filed May 4, 1962 3 Sheets-Sheet 2

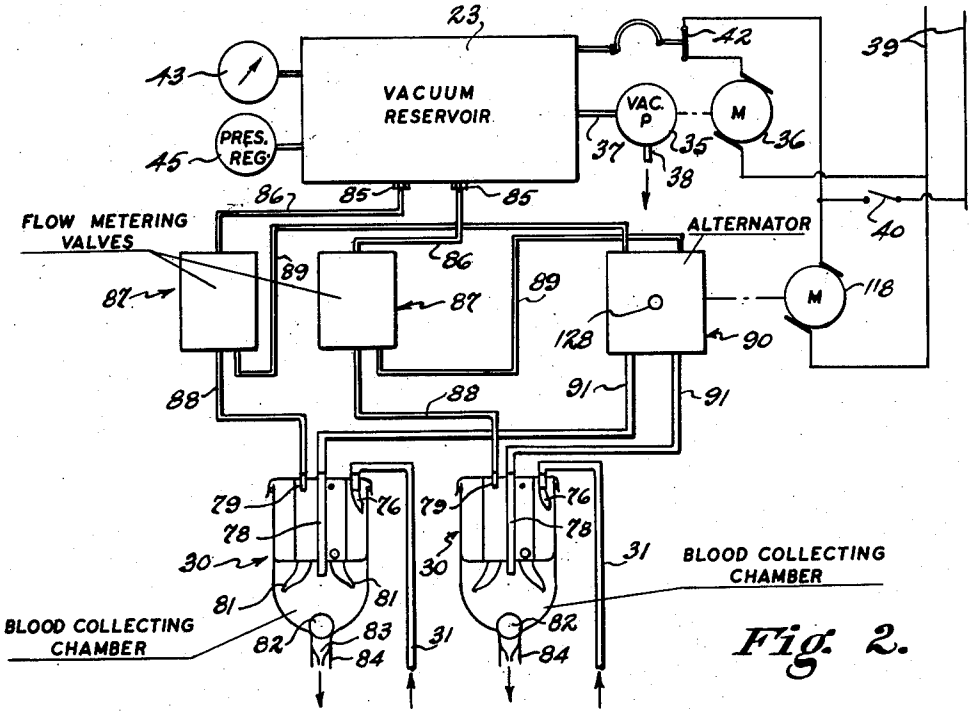


Fig. 2.

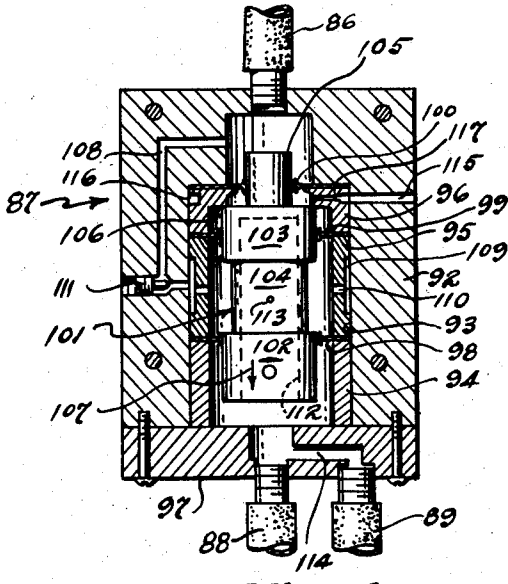

Fig. 8.

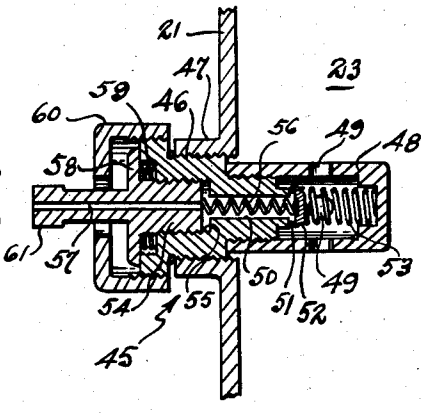

Fig. 9.

INVENTOR.
HAZEN F. EVERETT
BY Alvin Sinderbrand
ATTORNEY

June 29, 1965 H. F. EVERETT 3,191,600

BLOOD SUCTION APPARATUS

Filed May 4, 1962 3 Sheets-Sheet 3

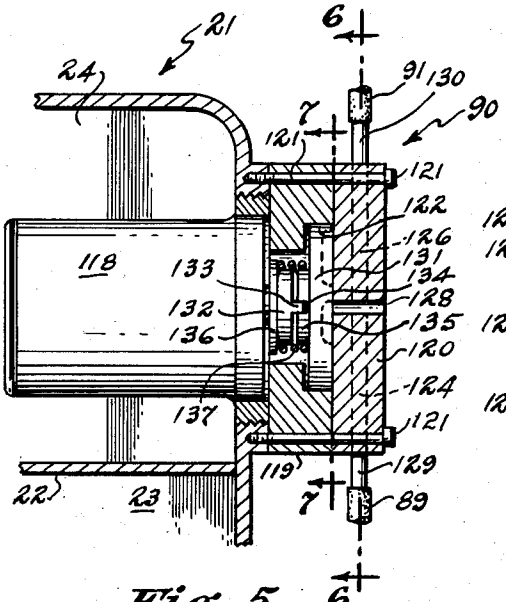


Fig. 5.

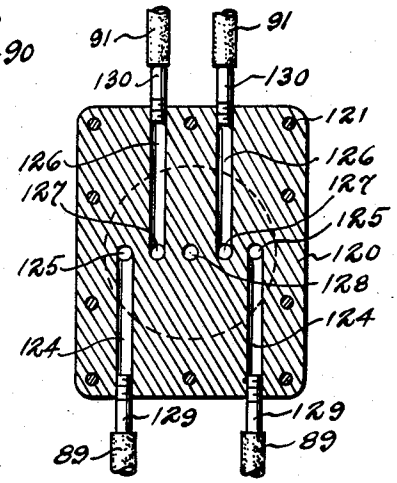


Fig. 6.

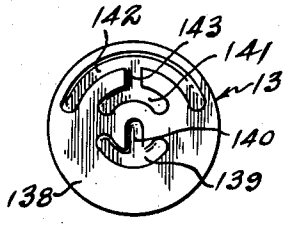


Fig. 7.

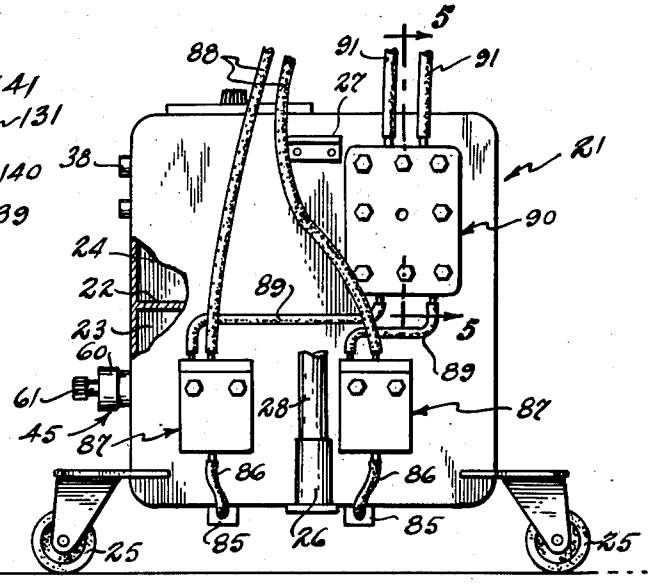


Fig. 3.

INVENTOR.
HAZEN F. EVERETT

BY

ATTORNEY

United States Patent Office 3,191,600 Patented June 29, 1965



3,191,600

# BLOOD SUCTION APPARATUS

Hazen F. Everett, 120 Bedford Road, Hillsdale, N.J.

Filed May 4, 1962, Ser. No. 192,519
16 Claims. (Cl. 128—276)

This invention relates generally to a blood suction apparatus for withdrawing blood from a surgical field and returning the blood to a pump-oxygenator or the like. for example, as in the case of cardiac surgery.

Although various blood suction apparatuses have been proposed heretofore, such existing apparatuses all fail to fully satisfy the necessarily exacting requirements for a blood suction apparatus, either with respect to convenience and reliability in actual use or with respect to the avoidance of haemolysis or other traumatic action on the blood or the return of foam.

Accordingly, it is an object of this invention to provide an improved blood suction apparatus which meets the necessarily stringent requirements imposed upon an apparatus of the described character, both as to its convenience and reliability in use and as to the atraumatic return of foamless intracardiac blood to a pump-oxygenator or the like.

More specifically, it is an object of this invention to provide an apparatus of the described character in which blood is removed from the surgical field through a plurality of suction tips which are continuously communicated with a vacuum reservoir embodied in the apparatus, and wherein the rate of flow through each tip is automatically metered to provide a large rate of flow when the individual tip is immersed in a pool of blood for rapidly withdrawing large volumes of blood from the surgical field, and to very substantially reduce the rate of flow through the tip when the latter is more or less open to the atmosphere, thereby to minimize the amount of air drawn into the suction tip for avoiding excessive foaming of the residue of blood being taken in by the tip and further to avoid any sharp reduction of the vacuum maintained in the vacuum reservoir.

Another specific object is to provide an apparatus of the described character having blood collecting chambers for continuously receiving blood from the associated suction tips, and from which the collected blood is intermittently and automatically allowed to drain, with the collecting chambers being constructed and arranged for effecting the very efficient defoaming of the blood which drains therefrom for return to a pump-oxygenator or the like.

A further object is to provide an apparatus of the described character in which the number of parts or components coming in contact with the blood during operation of the apparatus is held to a minimum, and such parts or components are arranged for convenient sterilization thereof.

In accordance with an aspect of this invention, each blood collecting chamber is divided into upper and lower compartments and has check or one-way valves leading from the upper compartment to the lower compartment and from the lower compartment into a drain tube, with the upper compartment being in continuous communication with the vacuum reservoir, while the lower compartment is alternately communicated with the vacuum reservoir and vented to the atmosphere through a continuously operated alternator. Thus, any blood in the region of the associated suction tip is continuously drawn into the latter and then through a blood inlet tube into the upper compartment, and the blood in the upper compartment drains from the latter into the lower compartment during each interval when the latter is under suction, and thereafter drains from the lower compartment when the latter is vented to the atmosphere.



In order to assist in defoaming of the blood returned to a pump-oxygenator or the like, each blood collecting chamber has a spacer tube in its upper compartment dividing the latter into inner and outer spaces which communicate with each other primarily through one or more openings in the bottom portion of the spacer tube, and the blood inlet tube opens into the outer space of the upper compartment while blood drains into the lower compartment from the inner space of the upper compartment so that any foam admitted with blood to the outer space of the upper compartment rises to the top of the outer space and only blood passes from the latter through the opening or openings in the spacer tube into the inner space for draining into the lower compartment. Further, the lower compartment of the blood collecting chamber is provided with a hemispherical wall and blood draining from the upper compartment into the lower compartment is directed against the hemispherical wall to flow smoothly along the latter and further release any entrapped air. The return of foam to the associated pump-oxygenator or the like is further prevented by providing a buoyant ball check valve associated with the blood discharge opening at the bottom of the lower compartment of the blood collecting chamber so that the ball check valve floats on the surface of the body of blood in the lower compartment and is effective to close the discharge opening when the body of blood in the lower compartment is almost depleted and before any foam on the surface of the body of blood in the lower compartment can reach the discharge opening.

In accordance with another important aspect of this invention, the suction lines or conduits leading to each of the blood collecting chambers from the suction or vacuum reservoir have an automatic flow metering valve interposed therein, and each flow metering valve includes a valve spool movable axially, under the influence of differences in the pressures acting against its opposite ends, between a first or closed position which the valve spool occupies when the associated suction tip is more or less open to atmosphere to provide the desired relatively low flow rate, thereby to avoid a substantial loss of vacuum in the reservoir and also to avoid trauma to the blood as a result of violent sucking of blood and air together into the suction tip, and a second or open position occupied when the associated suction tip is fully submerged in blood to provide the desired high flow rate for effectively removing large volumes of blood from the surgical field.

The above, and other objects, features and advantages of the invention, will be apparent in the following detailed description of an illustrative embodiment thereof which is to be read in connection with the accompanying drawings forming a part hereof, and wherein:

FIG. 1 is a perspective view of a blood suction apparatus embodying the present invention;

FIG. 2 is a diagrammatic view of the various components included in the apparatus of FIG. 1;

FIG. 3 is an end elevational view of a base included in the apparatus of FIG. 1 and defining a combined housing and vacuum reservoir;

FIG. 4 is a vertical sectional view of one of the blood collecting chambers included in the apparatus of FIG. 1;

FIG. 5 is an enlarged sectional view taken along the line 5—5 on FIG. 3 and showing an alternator included in the apparatus embodying the invention;

FIGS. 6 and 7 are detail sectional views taken along the line 6—6 and the line 7—7, respectively, on FIG. 5;

FIG. 8 is an enlarged axial sectional view of one of the automatic flow metering valves included in the apparatus of FIGS. 1 and 2;

FIG. 9 is an enlarged axial sectional view of a vacuum regulating valve also included in the apparatus of FIGS. 1 and 2;

FIG. 10 is a side elevational view of a combined handle and shut-off valve provided for each of the suction tips of the apparatus of FIG. 1, and which is shown in its closed position;

FIG. 11 is an axial sectional view of the combined handle and shut-off valve of FIG. 10, but shown in its open position;

FIG. 12 is an enlarged perspective view of a valve element included in the combined handle and shut-off valve of FIGS. 10 and 11;

FIG. 13 is an enlarged axial sectional view of a suction tip that can be used with the apparatus of FIG. 1;

FIG. 14 is a perspective view of a molded plastic body from which each of several check valves included in the apparatus of FIG. 1 is preferably formed;

FIG. 15 is a sectional view illustrating a step in the forming of a check valve from the body of FIG. 14; and

FIG. 16 is a perspective view of the completed valve formed from the body of FIG. 14.

Referring to the drawing in detail, and initially to FIG. 1 thereof, it will be seen that a blood suction apparatus embodying the present invention, and there generally identified by the reference numeral **20**, includes a base **21** which is preferably in the form of a welded box having a horizontally extending partition **22** therein (FIGS. 3 and 5) dividing the interior of the box into a sealed lower compartment **23** forming a vacuum reservoir and an upper compartment **24** for accommodating the various electrical components of the apparatus **20**. The base **21** is preferably mounted on casters **25** to facilitate movement of the apparatus to a suitable location adjacent an operating table. Brackets **26** and **27** (FIG. 3) are secured at one end of base **21** to support a vertical post **28** (FIGS. 1 and 3) carrying a vertically adjustable support **29** in which two blood collecting chambers **30** are removably suspended.

A flexible blood inlet tube **31**, preferably of a surgical grade of polyvinylchloride, extends from each of the blood collecting chambers **30** through an associated combined handle and shut-off valve **32** to a suction tip **33**. A hanger rod **34** is also adjustably carried by the support **29** and is adapted to engage tubes **31** for supporting at least part of the weight thereof when the suction tips **33** are suitably positioned at a surgical field for withdrawing blood from the latter.

Referring now to FIG. 2 of the drawings, it will be seen that the apparatus **20** further generally includes a vacuum pump **35** driven by a shaded pole electric motor **36**. Pump **35** and its motor **36** are both mounted in the upper compartment **24** of base **21** and the pump has its inlet **37** connected to vacuum reservoir **23** while its outlet is connected to a vent opening **38** in a side wall of base **21** so that pump **35** is continuously operative during energization of its motor **36** to evacuate air from reservoir **23**.

The energizing circuit for motor **36** includes conductors housed in the usual cable **39** for connection to power supply lines. Interposed in the energizing circuit are an on-off switch **40** which is manually operable through a control knob **41** (FIG. 1) on the top of base **21**, and a normally closed pressure sensitive safety switch **42** which is responsive to the vacuum in reservoir **23** to open and thus halt operation of motor **36** when the vacuum in the reservoir exceeds a predetermined value, for example, 80 mm. Hg. A pressure gauge **43** (FIG. 2) is also disposed within the upper compartment **24** of base **21** so as to be visible through a transparent panel or window **44** in the top of the base, and the gauge **43** is suitably connected to the vacuum reservoir **23** to indicate the vacuum in the latter.

The vacuum maintained within reservoir **23** is determined by a pressure regulator **45** which is preferably



mounted in a side wall of base **21** and has the construction illustrated in detail on FIG. 9. The pressure regulator **45** includes a body **46** screwed into an internally threaded flange **47** extending around an opening in the side wall of base **21**. A tubular cage **48** is screwed onto a reduced diameter inner end portion of body **46** and has radial openings **49** establishing communication between vacuum reservoir **23** and the interior of cage **48**. Body **46** has an axial bore **50** extending therethrough and a valve seat **51** is provided at the inner end of bore **50**. A valve disk **52** movable within cage **48** is urged against valve seat **51** by a helical spring **53** which bears against the inner end of cage **48**. An adjusting member **54** is screwed into a threaded counterbore **55** formed in the outer end portion of body **46** and acts against a helical adjusting spring **56** which is disposed in bore **50** between adjusting member **54** and valve disk **52**. The adjusting member **54** has an axial passage **57** extending therethrough and further is formed with a radial, outwardly directed flange **58** intermediate its ends. A friction spring **59** is disposed in an annular recess at the outer end of body **46** and bears against flange **58** of adjusting member **54** to frictionally hold the setting of the latter relative to body **46**. A centrally apertured cap **60** is screwed on the outer end of body **46** so that axial adjustment of member **54** caused by turning of the latter relative to body **46** is limited through engagement of flange **58** either with the outer end face of body **46** or the inner surface of cap **60**. The outer end of adjusting member **54** which projects through the central aperture of cap **60** is preferably knurled, as at **61** (FIG. 3), to facilitate manual rotation of member **54**, and hence axial adjustment of the latter, relative to body **46**.

It is apparent that the described axial adjustment of member **54** varies the force exerted by spring **56** on valve disk **52** in opposition to the seating force of spring **53**. Thus, atmospheric pressure acting on disk **52** through passage **57** and bore **50** combines with the adjustable force of spring **56** to overcome the seating force of spring **53** when the vacuum within reservoir **23** exceeds a predetermined value which may be adjusted by turning of the adjusting member **54**.

Referring now to FIG. 4, it will be seen that each of the blood collecting chambers **30** preferably includes a hollow receptacle **62** formed of polypropylene or other suitable plastic having a substantially hemispherical lower portion **63** with a central depending discharge opening or neck **64**. A diaphragm or partition **65** preferably formed from a surgical grade of polyvinylchloride is disposed tightly within receptacle **62** and extends substantially across the middle of the latter for dividing the interior of each blood collecting chamber **30** into an upper compartment **66** and a lower compartment **67**. The upper end of receptacle **62** is closed by a metal cap **68** having a depending rim **69** which is circumferentially ridged to accommodate an elastomeric ring **70** providing a hermetic seal. A spacer tube **71** of substantially smaller diameter than the receptacle **62** depends from cap **68** so that, when the latter is positioned on receptacle **62**, the upper compartment **66** is divided into an inner space **72** within spacer tube **71** and an outer annular space **73** between spacer tube **71** and the side wall of receptacle **62**. A small vent opening **74** is provided near the top of spacer tube **71** to maintain equal pressures in the inner and outer spaces **72** and **73**, and tube **71** further has one or more relatively large openings **75** near its lower edge to permit flow of blood from outer space **73** into inner space **72** at a level immediately above partition or diaphragm **65**.

Blood drawn from the surgical field through each suction tip **33** and blood inlet tube **31** is admitted to the related chamber **30** at outer space **73** of upper compartment **66** through a metal connecting tube **76** which is welded or brazed in cap **68**. The flexible blood inlet tube **31** tightly engages over the upper end portion of the metal connecting tube **76**, while the lower end portion of the latter with-

in space 73 is bent toward the adjacent side wall of receptacle 62 and obliquely cut, as at 77, so that the lower open end of tube 76 is in a plane substantially parallel to the adjacent side wall of the receptacle to cause the discharged blood to stream down the side wall and thereby tend initially to remove entrapped bubbles of air from the blood. The cap 68 further has a relatively long, centrally disposed metal connecting tube 78 brazed or welded therein to extend tightly through a central opening in the diaphragm 65 and open below the latter into the lower compartment 67. A third, relatively short metal connecting tube 79 extends through cap 68 and opens below the latter within spacer tube 71, that is, within the inner space 72 of upper compartment 66.

As hereinafter described in detail, the connecting tube 79 is continuously communicated with vacuum reservoir 23 so that the inner space 72 and, through the vent opening 74 of spacer tube 71, also the outer space 73 of upper compartment 66 are continuously subjected to a vacuum or sub-atmospheric pressure thereby to draw any blood in the region of the related suction tip 33 through the latter and the related blood inlet tube 31 into outer space 73. Since any foam admitted with blood to the outer space 73 rises towards the top of the latter, it is apparent that only liquid blood flows through opening or openings 75 from outer space 73 into inner space 72. Further, as hereinafter described in detail, connecting tube 78, and hence the lower compartment 67, is alternately communicated with vacuum reservoir 23 and vented to the atmosphere.

As shown in FIG. 4, blood outlet tubes 80 depend from the central portion of diaphragm 65, that is, from within inner space 72, at diametrically opposed locations and are inclined towards the adjacent side wall of receptacle 62. Each blood outlet tube 80, which also may be formed of a surgical grade of polyvinylchloride, terminates in a check or one-way valve 81 which permits a flow therethrough only in the direction from the upper compartment 66 into the lower compartment 67. Each valve 81 is designed, as hereinafter described in detail, so as to open under the weight of the blood in upper compartment 66 only when the upper and lower compartments are both subjected to vacuum, thereby to permit the blood to drain into lower compartment 67. However, when lower compartment 67 is vented to the atmosphere, atmospheric pressure acting against the outer surfaces of each valve 81 is effective to close the latter.

It will be noted that the valves 81 at the ends of blood outlet tubes 80 open adjacent the wall of receptacle 62 at the top of the hemispherical portion 63 thereof so that the blood draining into lower compartment 67 is made to flow in sheets or stream along the hemispherical lower portion 63 thereby to further encourage the release of air bubbles therefrom. In order to further prevent the discharge of foam from lower compartment 67, there is provided within the latter a buoyant ball valve 82 which is intended to float on the surface of blood drained into lower compartment 67 from upper compartment 66, and the ball valve 82 is dimensioned to close the discharge opening or neck 64, as shown in FIG. 4, when the level of blood nears discharge opening 64 so that foam floating on the blood cannot exit through the discharge opening.

A check or one-way valve 83 which is similar to each of the valves 81 is provided on the discharge opening or neck 64 to permit flow through the latter only in the direction out of lower compartment 67 into a return pipe or tube assembly 84 also preferably formed of polyvinylchloride and through which the collected blood may be returned to a pump-oxygenator (not shown) or the like. It will be apparent that, by reason of the valve 83, blood can drain from the lower compartment 67 through the return pipe assembly 84 only when lower compartment 67 of the related blood collecting chamber 30 is vented to the atmosphere. However, when lower compartment 67 is communicated with vacuum reservoir 23, atmospheric pressure acting on the outside of valve 83 through the return pipe or tube assembly 84 positively effects closing of the one-way valve.



Referring again to FIG. 2, it will be seen that vacuum reservoir 23 is provided with vacuum connections 85, preferably located at the bottom of base 21 (FIG. 3), and from which tubes 96 extend to associated flow metering valves generally identified by the reference numerals 87. A flexible tube 88, preferably of a polyvinylchloride, extends from each flow metering valve 87 to the connecting tube 79 of the related blood collecting chamber 30, and each flow metering valve 87 further has a tube 89 extending therefrom to an alternator generally identified by the reference numeral 90. Flexible tubes 91 also extend from the alternator 90 to the connecting tubes 78 of the blood collecting chambers 30. The flow metering valves 87 and alternator 90 are preferably mounted on base 21, for example, on one end wall thereof, as shown in FIG. 3.

The purpose of the alternator 90 is to alternately establish communication between the lower compartments 67 of collecting chambers 30 and vacuum reservoir 23 and between the lower compartment 67 and the atmosphere, while the function of each flow metering valve 87 is to vary the rate of flow of air therethrough back to vacuum reservoir 23 so that, when the related suction tip 33 is immersed in a pool of blood, a high rate of flow is permitted to effect the removal of large volumes of blood whereas, when the related suction tip 33 is more or less open to the atmosphere, the permitted rate of flow is very substantially reduced, thereby to permit the suction tip to remove any residue of blood in its immediate vicinity while avoiding the violent sucking in of such blood together with large volumes of air which would result in trauma to the blood as well as in the excessive foaming thereof.

As shown particularly in FIG. 8, each of the flow metering valves 87 preferably includes a body 92 having a generally cylindrical cavity 93 therein which receives liners 94, 95 and 96 and is closed, at one end, by a cover 97. Sealing rings 98, 99 and 100 of silicone rubber or the like are positioned by the liners and extend radially inward therefrom to slidably engage related portions of a valve spool 101. Valve spool 101 includes relatively large diameter portions 102 and 103 with a reduced diameter portion 104 therebetween and a still further reduced diameter end portion 105 extending from portion 103. Sealing rings 99 and 100 continuously engage portions 103 and 105 of the valve spool, while portion 102 of the valve spool is axially dimensioned so that sealing ring 98 engages the surface thereof when portion 103 seats against a radial shoulder 106 formed on liner 96 but rides off portion 102 when valve spool 101 is axially displaced in the direction of arrow 107 on FIG. 8, that is, in the direction away from shoulder 106.

The tube 86 extending from vacuum reservoir 23 opens into the cavity 93 of flow metering valve 87 at the end of the cavity containing reduced diameter end portion 105 of the valve spool so that the predetermined vacuum in the reservoir always acts against the relatively small end surface of portion 105. A bypass 108 is formed in body 92 and extends from the end of cavity 93 at which tube 86 opens into an intermediate portion of the cavity containing liner 95 between seals 98 and 99. The outer surface of liner 95 is formed with a circumferential groove 109 located to register with bypass 108 and having radial bores 110 opening inwardly between seals 98 and 99. An adjustable needle valve 111 is interposed in bypass 108 so as to define a variable orifice in the latter.

Valve spool 101 is further formed with an axial blind bore 112 opening at the large diameter end of the valve spool defined by portion 102, and a small radial orifice 113 opens from blind bore 112 at the reduced diameter portion 104 between portions 102 and 103.

The tubes 88 and 89 extending from flow metering valve 87 directly to the associated chamber 30 and to the latter through the alternator 90, respectively, open

through passages 114 in the cover 97 into the end of the cavity 93 containing sleeve or liner 94. Finally, valve body 92 is provided with a vent 115 to the atmosphere in alignment with an annular groove 116 in the outer surface of liner 96 which further has one or more radial passages 117 extending from groove 116 and opening at the inner surface of liner 96 between shoulder 106 and seal 100.

The operation of the above described flow metering valve 87 is as follows:

When the associated suction tip 33 is open to the atmosphere, atmospheric pressure acts upon the relatively large diameter end of spool 101 through suction tip 33, tubes 31 and 76, upper compartment 66 of the related blood collecting chamber 30, and tubes 79 and 88, so that the force due to atmospheric pressure acting on the large diameter end of spool 101 moves the latter until portion 103 of the spool engages shoulder 106, as shown in FIG. 8. In the illustrated position of valve spool 101, air can flow from tubes 88 and 89 through metering valve 87 only at the slow rate of flow determined by the size of the fixed orifice 113. Thus, if the associated suction tip 33 is more or less open to the atmosphere, that is, not immersed in a pool of blood, air is drawn into the suction tip only at the low rate of flow determined by fixed orifice 113, so that although suction continues to be available at the suction tip for drawing in any residual blood in the vicinity thereof, there is no danger that large volumes of air will be sucked in through the tip 33 to either substantially reduce the value of the vacuum in reservoir 23 or to produce traumatic conditions in the handling of the blood.

On the other hand, when the associated suction tip 33 is immersed in a pool of blood, which thereby provides a liquid seal from the atmosphere at the tip 33, the vacuum in reservoir 23 then also acts at the large diameter end of spool 101 through bypass 108, variable orifice 111 and fixed orifice 113. Since the predetermined vacuum or sub-atmospheric pressure is then acting at both the large and small diameter ends of spool 101, there is a resulting force in the direction of the arrow 107 moving the valve spool 101 away from shoulder 106 until seal 98 rides off large diameter portion 102 of the valve spool, whereupon a substantial annular space is created between seal 98 and the reduced diameter portion 104 of the value spool so that a high rate of flow can occur through such annular space, with the high rate of flow being limited only by the adjustment of the variable orifice 111. Accordingly, when the associated suction tip 33 is immersed in a pool of blood, a high rate of flow is available for drawing in large volumes of blood through the suction tip. It is to be noted that the change between the high and low rates of flow permitted through each suction tip 33 is effected automatically by the metering flow valve 87 and thus does not require any attention from the surgeon or assisting personnel.

The alternator 90 is driven by a synchronous capacitor electric motor 118 which, as shown in FIG. 2, is also energized from the usual power supply lines through the conductors 39 so that the motor 118 is continuously operated so long as the manually actuated switch 40 is in its closed position.

As shown particularly in FIG. 5, the alternator 90 includes a body 119 and a ported cover block 120 which are secured together in face-to-face relation and jointly mounted on the upper portion of an end wall of base 21 by bolts 121 screwed into tapped holes in the base. The outer surface of body 119, that is, the surface confronting block 120, is formed with a circular recess 122, and body 119 further has a bore 123 which is coaxial with recess 122 and extends from the latter to the inner face of body 119. As shown particularly in FIG. 6, cover block 120 is formed with a pair of relatively widely spaced apart, parallel passages 124 extending upwardly from the lower edge of block 120 to the center of the latter and there terminating in ports 125 opening at the inner surface of block 120 at diametrically opposed locations within the recess 122 of body 119. Block 120 is further formed with a pair of parallel passages 126 spaced apart by a distance substantially less than that between the passages 124 and extending downwardly from the upper edge of block 120 to the center of the latter where the passages 126 terminate in ports 127 also opening at the inner surface of the cover block between ports 125 at diametrically opposed locations within recess 122. Finally, block 120 is provided with a bore 128 extending therethrough and being centered with respect to recess 122 and also with respect to ports 125 and 127 to constitute a vent opening.

The tubes 89 extending from flow metering valves 87 engage connecting tubes or nipples 129 screwed into the lower ends of passages 124, while the tubes 91 which extend to the blood collecting chambers 30 engage connecting tubes or nipples 130 screwed into the upper ends of passages 126.

The alternator 90 further includes a circular rotor 131 (FIGS. 5 and 7) which is preferably formed of nylon and is freely rotatable within recess 122 of body 119. The motor 118 is suitably mounted within the upper compartment 24 of base 21 in axial alignment with rotor 131 and is preferably provided with reduction gearing so that, when rotor 131 is rotatably coupled to motor 118 as hereinafter described in detail, the rotor is rotated at a suitable slow speed, for example, 10 revolutions per minute. As shown in FIG. 5, the output shaft of the reduction gearing in motor 118 has a drive member 132 secured thereon and extending into the bore 123 of body 119. Drive member 133 has a diametrically extending key 133 projecting from its outer end surface and slidably engaging in a similar diametrically extending groove 134 formed in a hub 135 on the inner side of rotor 131 so that the latter is rotated through the engagement of key 133 in slot 134. Drive member 132 is further formed with an outwardly extending flange 136 providing a seat for one end of a helical compression spring 137 which bears, at its other end, against rotor 131 around hub 135 so that spring 137 continuously urges rotor 131 axially against the inner surface of the ported cover block 120 for sealing engagement with the latter.

As shown in FIG. 7, the outer surface 138 of rotor 131, that is, the surface thereof in slidable sealing engagement with cover block 120, is formed with an arcuate groove 139 concentric with the rotor and having a radius of curvature equal to the distance between each port 127 and the central vent opening 128 of block 120. The arcuate groove 139 has an angular extent of slightly less than 180°. A radial groove 140 in surface 138 extends from the arcuate groove 139 to the center of rotor 131 so that the inner end of radial groove 140 registers continuously with vent opening 128 and thereby maintains communication between groove 139 and the atmosphere. Surface 138 of rotor 131 further has an arcuate groove 141 of the same curvature and angular extent as groove 139, but diametrically opposed to the latter, and an arcuate groove 142 of larger radius of curvature for registration with the ports 125 of cover block 120 and being connected through a radial groove 143 with the arcuate groove 141.

It will be apparent that, as rotor 131 is rotated in recess 122, for example, at the previously mentioned speed of 10 revolutions per minute so that 6 seconds is required for each complete revolution, grooves 139 and 140 establish communication between the vent opening 128 and one of the ports 127 of block 120 during one-half of each revolution so that the lower compartment 67 of the associated blood collecting chamber 30 is then vented to the atmosphere, while grooves 141, 142 and 143 establish communication between the other port 127 and the adjacent port 125 so that the lower compartment 67 of the other blood collecting chamber is then con-

nected or communicated with vacuum reservoir 23 through the associated flow metering valve 87. During the remaining half of the complete revolution of rotor 131, the connections to vacuum and atmosphere are reversed so that the blood collecting chamber 30 having its lower compartment 67 previously vented to atmosphere is then communicated with the vacuum reservoir 30, while the lower compartment of the blood collecting chamber previously communicated with the vacuum reservoir is then vented to the atmosphere. Accordingly, the lower compartments 67 of the two blood collecting chambers 30 are alternately communicated with the vacuum reservoir and vented to atmosphere during each revolution of rotor 131. As previously described herein, blood drains from the upper compartment 66 of each blood collecting chamber 30 into the lower compartment 67 when the latter is communicated with the vacuum reservoir 23, and the blood drains from the lower compartment 67 into the return pipe assembly 84 when the lower compartment 67 is vented to the atmosphere during each revolution of rotor 131.

Referring now to FIGS. 10 and 11, it will be seen that the combined handle and shut-off valve 32 provided for each of the suction tips 33 preferably includes an elongated metal body 144 having an axial bore 145 extending therethrough and being diametrically enlarged, at one end, as at 146 (FIG. 11). Each suction tip 33 is in the form of a length of suitably bent stainless steel tubing having an adapter 147 at one end fitting into the enlarged end portion 146 of bore 145 and being removably secured therein by a set screw 148 extending through body 144 and engaging in an annular groove 149 in adapter 147. Adapter 147 further has a nipple 150 extending therefrom to tightly receive the end of the associated blood inlet tube 31 thereon.

Body 144 is further formed with a laterally extending bore 151 opening at one side of the body to closely receive a pinch valve member 152. As shown in FIG. 12, pinch valve member 152 includes a pair of parallel spaced apart end disks 153 joined together by a connecting portion 154 having the configuration of a segment of a cylinder with a lug 155 projecting radially from the connecting portion 154 adjacent one edge of the latter.

Body 144 further has a laterally opening cutout 156 FIG. 10) contiguous to the bore 151 so that pinch valve member 152 can be inserted into, and removed from bore 151 only when the valve member is turned to a position in which its lug 155 is received in cutout 156. The top of body 144 also has a longitudinally extending slot 157 therein formed with rabbetted side edges and opening, at its back end, into a relatively wider opening 158 (FIG. 11). A finger operated actuating member 159 is provided with a slide 160 at its underside which is formed with rabbetted side edges slidably engageable with the rabbetted side edges of slot 157 so that the actuating member is movable along the top of body 144 between the positions illustrated in FIGS. 10 and 11, respectively, and is disengageable from slot 157 by movement rearwardly beyond the position of FIG. 10 so that its slide 160 moves into the opening 158.

In assembling together the several elements of the combined handle and shut-off valve 32, the slide 160 of actuating member 159 is first engaged in, and moved forwardly along slot 157, and valve member 152 is then inserted in bore 151 with its lug 155 passing through cutout 156. When valve member 152 is fully disposed in bore 151, it is turned to the position shown in FIG. 11 with its lug 155 projecting upwardly in opening 158. In that position of valve member 152, the connecting portion 154 thereof is disposed at the top so that the space between end disks 153 is substantially aligned with bore 145 and the flexible tube 31 can then be extended through the unobstructed bore 145 of body 144. With the free end of tube 31 projecting from body 144, such free end can be easily engaged on the nipple 150 of adapter 147, and the tube 31 is thereafter drawn back into body 144 so that the adapter 147 enters the enlarged end 146 of bore 145 and is secured therein by tightening of set screw 148. The tube 131 thus positioned within bore 145 between the end disks 153 of valve member 152 prevents removal of the valve member from its bore 151 and, so long as valve member 152 is disposed in its bore 151, the lug 155 of the valve member prevents inadvertent removal of the slide 160 of actuating member 159 from the slot 157. However, it will be obvious that the various elements making up the combined handle and shut-off valve 32 can be conveniently disassembled by reversing the steps of assembly described above, whereby such elements can be easily and thoroughly cleaned and sterilized.

When the actuating member 159 is in its forward position illustrated in FIG. 11, tube 31 is unobstructed or fully open so that blood can flow freely therethrough from the associated suction tip 33. However, when actuating member 159 is moved rearwardly, that is, away from the end of body 144 in which adapter 147 is secured, for example, to the position shown on FIG. 10, the actuating member 159 acts against the lug 155 of valve member 152 to turn the latter within bore 151 and thereby cause the connecting portion 154 of the valve member to pinch tube 31 against the bottom of bore 145. When the tube 31 is thus pinched shut, the associated suction tip 33 is rendered inoperative.

The action of actuating member 159 on valve member 152 is irreversible so that valve member 152 remains in its closed position shown on FIG. 10 until member 159 is again manually displaced to the position of FIG. 11.

The end of suction tip 33 remote from adapter 147 may be merely provided with a central axial opening, or with both a central axial opening and a series of radially opening slots extending longitudinally in the end portion of the suction tip for permitting the entry of blood into the latter. However, as shown in FIG. 13, the end portion of suction tip 33 having an axial opening 161 therein is preferably surrounded by a bullet-shaped sleeve or jacket 162 which is screwed onto threads 163 provided on tip 33 at a location spaced from its axially opening end. Jacket 162 is formed with a plurality of circumferentially spaced apart longitudinal slots or elongated openings 164 extending into the nose of jacket 162 and also with longitudinally extending grooves 165 interspersed between slots 164. It has been found that, with the particular tip construction shown in FIG. 13, the slots 164 and grooves 165 cooperate to maintain an open path for blood into the axial opening 161 of the tube or tip 33 even when the latter is inserted into relatively confined spaces, for example, a chamber of the heart, or is otherwise in contact with flesh at the surgical field from which blood is to be withdrawn.

It is further to be noted that the one-way valves 81 and 83 associated with each of the blood collecting chambers 30 are preferably shaped or formed in a particular manner so as to be extremely sensitive and reliable in operation. In forming each of the valves, a suitably shaped hot form is dipped into polyvinylchloride so as to deposit a removable hollow body 166 (FIG. 14) on the form which can be stripped from the latter. The body 166 includes a cylindrical portion 167 of relatively large wall thickness and an outlet portion 168 which increases in diameter, and tapers or decreases in thickness toward its free end edge. The large diameter end of flaring portion 168 of the preformed body is then squeezed together or flattened by a split circular spring 169 (FIG. 15) and suspended by the latter in an oven for a sufficient period of time to permit the polyvinylchloride to set in this altered shape. In order to avoid sticking together of the edge portions of body 166 which are squeezed together by spring 169, a thin film of silicone is preferably applied at the inside of the edge of outlet portion 168. The completed valve 166*a* illustrated in FIG. 16 thus includes a cylindrical mounting portion 167*a* having a relatively thick

wall, and an outlet portion 168*a* changing gradually from the circular cross-section at mounting portion 167*a* to the flat configuration at the end edge of portion 168*a*. Since the wall thickness of outlet portion 168*a* decreases in the direction toward its free edge, the outlet portion has sufficient flexibility to ensure its opening and closing in response to minimum pressure differentials. Further, the side surfaces of outlet portion 168*a* have relatively large areas for exposure to the pressures at the inside and outside of the valve and thereby further ensure extreme sensitivity of the valve to even small differential pressures. Since the free edge of outlet portion 168*a* is set in its closed position by the spring 169 acting thereon during the heat setting of the valve, the latter has a spring-like action at its squeezed together edges tending to maintain the valve in its closed condition.

It will be noted that, in the described blood suction apparatus, the blood contacts only the suction tips 33, blood inlet tubes 31, blood collecting chambers 30 and return tube assembly 84. As previously described herein, the suction tips 33 and associated combined handles and shut-off valves 32 may be easily disassembled for thorough cleaning and sterilization. The blood collecting chambers 30 are also capable of being disassembled conveniently for sterilization of the various parts thereof, whereas the blood inlet tubes 31, return tube assembly 84, and the valves 81 and 83 may be disposable and replacements therefor sold in sterile condition.

It is further to be noted that described blood suction apparatus 20 does not require priming with blood or plasma, and thereby reduces the cost of heart surgery or the like in that blood need not be obtained from a blood bank or donors for the purpose of priming the suction apparatus. Further, the various tubes and openings through which the blood passes between the suction tips 33 and the return tube assembly 84 are all designed with uniformly large cross-sectional areas so that large volumes of blood can be drawn from the surgical field and returned to the associated pump-oxygenator or the like without requiring a relatively great vacuum, thereby to avoid haemolysis or other trauma of the blood. Since blood drains from the lower compartment 67 of each blood collecting chamber 30 only when that lower compartment is vented to the atmosphere, and since each cycle of venting of the lower compartments to the atmosphere and of communication with the vacuum reservoir is determined by the operation of the alternator 90, for example, with a complete cycle occurring each six seconds, there is no possibility of a siphon being formed from the blood collecting chambers which would result in the return of air or foam as well as blood. As previously indicated herein, the arrangement of each of the blood collecting chambers 30 is such as to ensure the removal of air bubbles from the returned blood and the trapping of foam within the blood collecting chambers so that only liquid blood is returned to the associated pump-oxygenator or the like through the return tube assembly 84.

Although an illustrative embodiment of the invention has been described in detail herein with reference to the accompanying drawings, it is to be noted that the invention is not limited to that precise embodiment, and that various changes and modifications may be effected therein by one skilled in the art without departing from the scope or spirit of the invention, which is intended to be defined by the appended claims.

What is claimed is:

1. In a blood suction apparatus, the combination of

(A) a source of vacuum having means tending to maintain the vacuum at a substantially constant value,

(B) a plurality of suction tips for immersion in pools of blood,

(C) means connecting said suction tips with said source so that vacuum is available at said suction tips for drawing blood into the latter, and

(D) pressure responsive flow metering means interposed in said connecting means between each of said suction tips and said source of vacuum, each of said flow metering means including a valve body having a cavity therein with ports communicating with said source of vacuum and the related suction tip, respectively, a valve spool moved in said cavity by differential pressures acting thereon through said ports between a first position occupied by said valve spool when the related suction tip is immersed in blood and a second position occupied by said valve spool when the related suction tip is substantially open to the atmosphere, and cooperative means in said valve body and spool defining a passage of relatively large cross-section between said ports when said spool is in said first position and defining a restricted passage between said ports when the spool is in said second position, thereby to permit a relatively high rate of flow into the related suction tip when the latter is immersed in blood and to substantially restrict the rate of flow into said related suction tip when the latter is open to the atmosphere, for avoiding substantial loss of vacuum at said source and the drawing in of large volumes of air with blood into said suction tips.

2. A pressure responsive flow metering device for regulating the rate of flow into a suction tip intended to be immersed in a body of liquid, said flow metering device comprising:

(a) a valve body having a cavity therein with a port at one of its ends adapted for connection to a source of vacuum and a port at its other end for connection to the suction tip,

(b) a valve spool movable axially in said cavity and having opposite ends of relatively small and large areas, respectively, facing toward said one end and said other end, respectively, of said cavity,

(c) means for bleeding vacuum from said one end to said other end of said cavity so that said spool is moved toward said one end of the cavity, when the related suction tip is open to the atmosphere, and said spool is moved toward said other end of the cavity, when both of said ends of the spool are exposed to vacuum by sealing of the related suction tip through immersion of the latter in a liquid, and

(d) cooperative means in said body and spool defining a passage therethrough of small cross-section to provide a restricted rate of flow into the suction tip, when said spool is moved toward said one end of the cavity, and defining a passage therethrough of relatively large cross-section to provide a high rate of flow into the suction tip, when said spool is moved toward said other end of the cavity.

3. In a blood suction apparatus, the combination of

(A) a tank having a continuously driven vacuum pump with an inlet connected to said tank so that the latter constitutes a vacuum reservoir,

(B) adjustable pressure regulating valve means connected to said vacuum reservoir for maintaining an adjustably predetermined vacuum in the latter,

(C) a plurality of suction tips for withdrawing blood from a surgical field,

(D) means connecting said suction tips with said vacuum reservoir so that vacuum is available at said tips for drawing blood into the latter, and

(E) pressure responsive flow metering means interposed in said connection means between each of said suction tips and said vacuum reservoir, each of said flow metering means including a valve body having a cavity therein with ports communicating with said vacuum reservoir and the related suction tip, respectively, a valve spool moved in said cavity by differential pressures acting thereon through said ports be-

tween a first position occupied by said valve spool when the related suction tip is immersed in blood and a second position occupied by said valve spool when the related suction tip is substantially open to the atmosphere, and cooperating means in said valve body and spool defining a passage of relatively large cross-section between said ports when said spool is in said first position and defining a restricted passage between said ports when the spool is in said second position, thereby to permit a relatively high rate of flow into the related suction tip when the latter is immersed in blood and to substantially restrict the rate of flow into said related suction tip when the latter is open to the atmosphere, for avoiding substantial loss of vacuum from said reservoir and the drawing in of large volumes of air with blood into said suction tips.

4. In a blood suction apparatus, the combination of

(A) a plurality of suction tips for withdrawing blood from a surgical field,

(B) a blood collecting chamber associated with each of said suction tips and having

(1) partition means dividing the interior of the chamber into upper and lower compartments,

(2) an inlet for blood in said upper compartment connected with the related suction tip,

(3) an outlet for blood at the bottom of said lower compartment, and

(4) one-way valve means between said compartments permitting flow only in the direction from said upper compartment into said lower compartment and at said outlet permitting flow through the latter only in the direction from said lower compartment,

(C) a source of vacuum,

(D) first conduit means continuously communicating said upper compartment of each blood collecting chamber with said source of vacuum so that vacuum is continuously available at the related suction tip for drawing blood through the latter into said upper compartment,

(E) second conduit means extending between said source of vacuum and said lower compartment of each blood collecting chamber, and

(F) alternator means having a vent to atmosphere and being interposed in said second conduit means, said alternator means being cyclically operative to alternately communicate said lower compartment of each chamber with said source of vacuum and with the atmosphere during respective portions of each operating cycle so that blood drains from said upper compartment into said lower compartment when the latter is in communication with said source of vacuum, and blood drains through said outlet of the lower compartment when the latter is in communication with the atmosphere.

5. In a blood suction apparatus, the combination as in claim 4;

further comprising flow metering means interposed in said first and second conduit means for each blood collecting chamber to permit a relatively high rate of flow therethrough when the related suction tip is immersed in blood and operative automatically to restrict the rate of flow through said conduit means when the related suction tip is open to the atmosphere, thereby to avoid substantial loss of vacuum at said source and further to avoid the drawing in of large volumes of air into said related suction tip along with blood.

6. In a blood suction apparatus, the combination as in claim 4, wherein said alternator means includes

(1) a ported block and a continuously rotated rotor engaging against a surface of said block,

(2) said block having said vent to the atmosphere opening at said surface thereof and being centered with respect to said rotor,

(a) said block further having first and second ports opening at said surface for each blood collecting chamber, with the ports associated with the respective blood collecting chambers being angularly spaced apart about the center of the rotor,

(b) said first and second ports being disposed different distances from said vent at the center of the rotor and being connected through said second conduit means with said source of vacuum and with said lower compartment of the related chamber, respectively, and

(3) said rotor having grooves therein opening against said surface of the ported block and disposed at diametrically opposed portions of the rotor to communicate said first and second ports with each other during approximately one-half of each revolution of said rotor and to communicate said second port with said vent to the atmosphere during the remaining half of each revolution.

7. In a blood suction apparatus, the combination as in claim 6;

wherein said first and second ports of the block associated with one of the blood collecting chambers are at one side of said vent and said first and second ports associated with another of said blood collecting chambers are at the diametrically opposite side of said vent so that the lower compartments of said one chamber and said other chamber are alternately communicated with said source of vacuum and vented to atmosphere.

8. In a blood suction apparatus, the combination as in claim 4;

(a) wherein each of said blood collecting chambers further includes a spacer tube in said upper compartment dividing the latter into outer and inner spaces,

(b) said inlet for blood opens into said outer space near the top of the latter, and said one-way valve means between the compartments extends from said inner space, and

(c) said spacer tube has at least one opening for blood passage therethrough adjacent said partition means so that any foam admitted with blood to said outer space rises toward the top of the latter and only blood passes through said opening of the spacer tube into said inner space for drainage from said upper compartment into said lower compartment.

9. In a blood suction apparatus, the combination as in claim 8;

wherein each blood collecting chamber further has a buoyant ball in said lower compartment adapted to float on blood in the latter and to close said outlet at the bottom of the lower compartment when the level of blood in the latter decreases below a predetermined point, thereby to prevent the drainage of foam through said outlet.

10. In a blood suction apparatus, the combination as in claim 8;

wherein each blood collecting chamber has a generally hemispherical lower wall portion, and said one-way valve means open into said lower compartment adjacent the top of said hemispherical lower wall portion so that blood streams smoothly along the latter from said valve means and turbulent foaming of the blood in said lower compartment is avoided.

11. In a blood suction apparatus, the combination as in claim 10;

wherein said inlet for blood into said outer space of the upper compartment is constituted by a metal tube having a terminal portion inclined toward the side wall of the blood collecting chamber with an obliquely cut end lying substantially parallel to said side wall so that the blood introduced into said outer space streams smoothly on said outer wall to avoid

excessive foaming of the blood and encourage the release of air bubbles from the latter.

12. In a blood suction apparatus, the combination as in claim 8;

(a) wherein a flexible blood inlet tube extends from each suction tip and communicates with said inlet of the related blood collecting chamber, and

(b) further comprising a combined handle and shut-off valve at the connection of each suction tip to the related inlet tube, so that each suction tip can be individually rendered operative and inoperative.

13. In a blood suction apparatus, the combination as in claim 12, wherein said combined handle and shut-off valve includes

(a) an elongated body having a longitudinal bore through which the inlet tube extends from the related suction tip,

(b) a pinch valve member turnable in said elongated body between an open position leaving said bore unobstructed and a closed position in which said valve member pinches shut said inlet tube in said bore, and

(c) a finger operated actuating member slidable on said body and engageable with said pinch valve member to turn the latter from said open position to said closed position of the latter.

14. In a blood suction apparatus, the combination as in claim 13;

(a) wherein said body further has a lateral bore opening at one side of the body and turnably receiving said pinch valve member,

(b) said pinch valve member straddles said inlet tube in said longitudinal bore and therefore is held in said lateral bore by said inlet tube, and

(c) said suction tip has an adapter at one end on which said inlet tube fits tightly, and said adapter is removably secured in one end of said longitudinal bore for holding said suction tip, inlet tube and combined handle and shut-off valve in assembled relation.

15. In a blood suction apparatus, the combination as in claim 4, wherein each of said one-way valve means consists of a one-piece body of plastic material having

(a) a cylindrical portion of relatively large wall thickness and hence substantial rigidity, and

(b) an outlet end portion having a wall thickness decreasing from said cylindrical portion to the free edge of said outlet end portion to render the latter substantially flexible,

(c) said outlet end portion having increasing circumferences toward said free edge and being flattened at the latter so that said outlet end portion is closed at said free edge, when the pressure outside of said body is greater than the pressure within said body, and said outlet end portion opens wide at said free edge when the pressure within said outlet end portion exceeds the pressure acting on the outside of the latter.

16. In a blood suction apparatus, the combination of

(A) a suction tip having an adapter at one end with a flexible blood inlet tube fitting tightly on said adapter for carrying blood from the associated tip, and

(B) a combined handle and shut-off valve comprising

(a) an elongated body having a longitudinal bore through which the inlet tube extends from the related suction tip and a lateral bore opening at one side of the body,

(b) a pinch valve member turnably received in said lateral bore and straddling said inlet tube in the longitudinal bore so that said pinch valve member is held in said lateral bore by said inlet tube, said pinch valve member being turnable between an open position leaving said longitudinal bore unobstructed and a closed position in which said valve member pinches shut said inlet tube in said longitudinal bore,

(c) a finger operated actuating member slidable on said body and engageable with said pinch valve member to turn the latter from said open position to said closed position of the pinch valve member, and

(d) means releasably securing said adapter of the suction tip in one end of said longitudinal bore for holding said suction tip, inlet tube and combined handle and shut-off valve in assembled relation.

**References Cited by the Examiner**

UNITED STATES PATENTS

| | | | |
|---|---|---|---|
| 864,158 | 8/07 | DeLany | 210—532 |
| 1,284,630 | 11/18 | Felsen | 128—276 |
| 2,376,794 | 5/45 | McCulloch | 55—178 |
| 2,574,135 | 11/51 | Ward | 32—33 |
| 2,652,831 | 9/53 | Chesler | 128—214 |
| 2,711,586 | 6/55 | Groves | 32—33 |
| 2,742,701 | 4/56 | Berger | 32—33 |
| 2,812,765 | 11/57 | Tofflemire | 128—276 |
| 2,900,978 | 8/59 | Johannisson | 128—276 |
| 2,927,582 | 3/60 | Berkman et al. | 128—214 |
| 2,986,098 | 5/61 | Trout et al. | |
| 3,016,055 | 1/62 | Oldenburg | 128—278 |
| 3,018,779 | 1/62 | Tyler et al. | 128—278 |
| 3,034,504 | 5/62 | Winsor et al. | 128—214 |

OTHER REFERENCES

American College of Surgeons, Surgical Forum, "The Use of a Vent for the Left Ventricle as a Means of Avoiding Air Embolism to the Systemic Circulation During Open Cardiotomy With the Maintenance of the Cardiorespiratory Function of Animals by a Pump Oxygenator," Bernard J. Miller et al., pp. 30–33, vol. 4, 1953.

RICHARD A. GAUDET, *Primary Examiner.*

JORDAN FRANKLIN, *Examiner.*