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Kletschka et al.

[11] **3,864,055**

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[54] **PUMPS CAPABLE OF USE AS HEART PUMPS AND BLOOD PUMPS**

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[22] Filed: **Nov. 9, 1973**

[21] Appl. No.: **414,225**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 204,980, Dec. 6, 1971, abandoned, which is a continuation-in-part of Ser. No. 886,137, Dec. 18, 1969, Pat. No. 3,647,324, which is a continuation-in-part of Ser. No. 678,265, Oct. 26, 1967, Pat. No. 3,487,784.

[52] **U.S. Cl.** .... **415/1,** 415/90, 415/DIG. 4, 3/DIG. 2, 128/214 R, 416/186

[51] **Int. Cl.** **F04d 7/00,** F04d 29/26

[58] **Field of Search** .. 415/215, 90, 186, 88, DIG. 4, 415/170 A, 1, 213; 3/DIG. 2; 128/214 R

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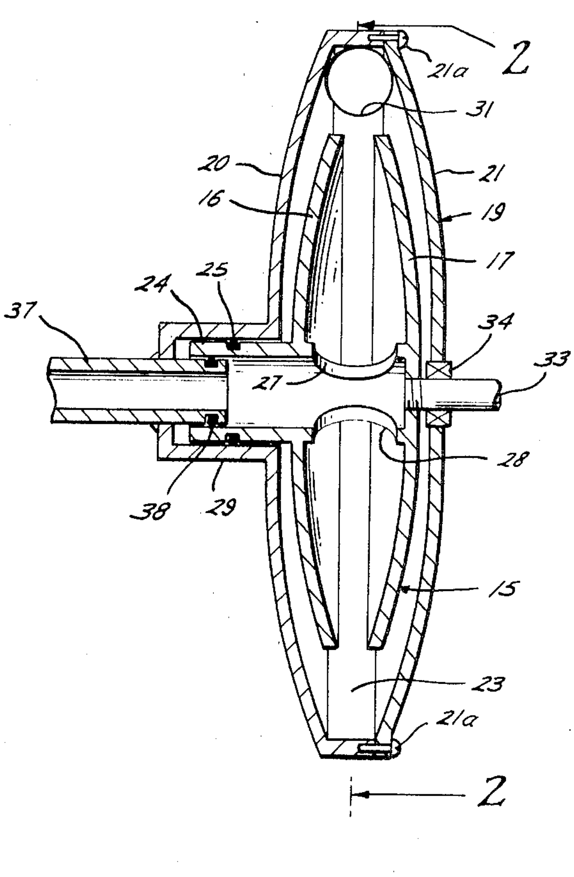
[57] **ABSTRACT**

Pumps and pumping methods wherein rotators having radial extent cause propulsion of the pumped fluid and wherein the rotators are outwardly convergent one toward another whereby the product, fluid volume times fluid velocity, at each radial location is substantially constant. The pumps are capable of use as heart pumps, blood pumps, and as pumps to pump all types of natural or artificial biological fluids in connnection with the maintenance of life and/or biological functions in a human body, animal body, or any other pumping function. The pumps can be used to replace or assist the pumping functions of the heart in vivo or ex vivo. The pumps can be used to pump biological fluids in vitro or in any in vivo, ex vivo, and in vitro combination. The pumps may be also used to pump natural or artificial biological fluids as well as nonbiological fluids. The nonbiological fluids so pumped may be pumped in connection with biological or nonbiological activities, functions, and/or applications.

12 Claims, 10 Drawing Figures



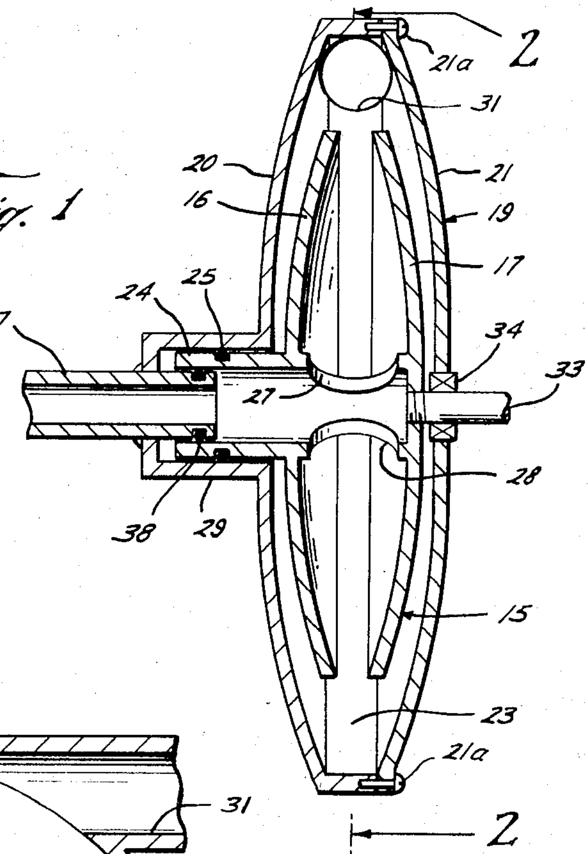
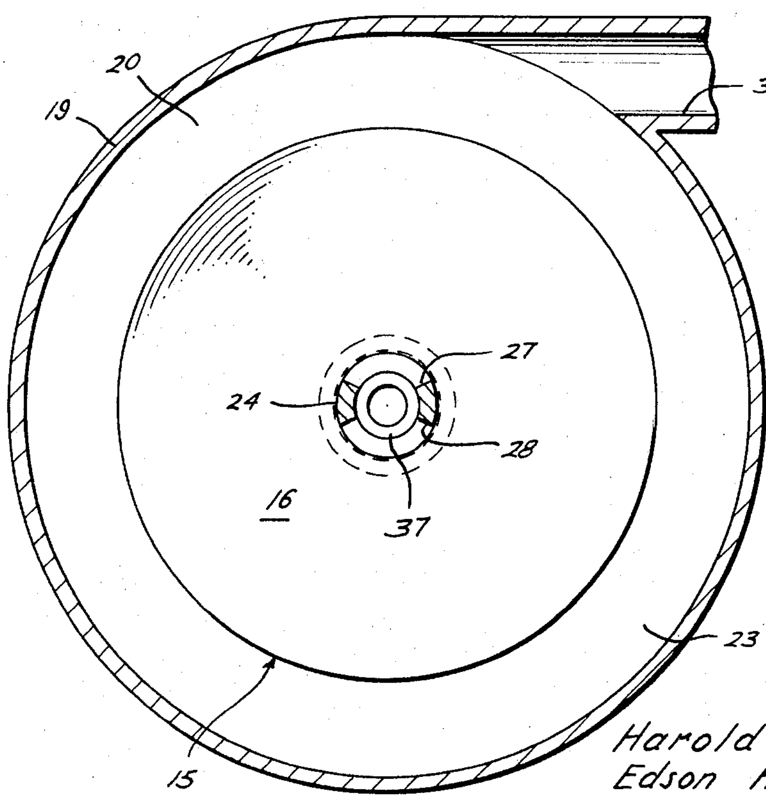


Fig. 1

Fig. 2



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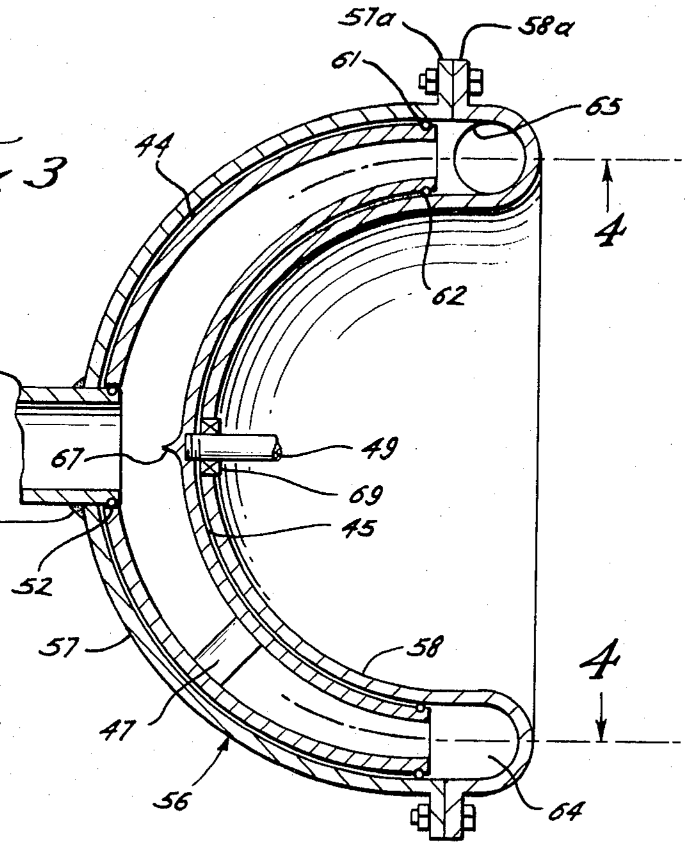

Fig. 3

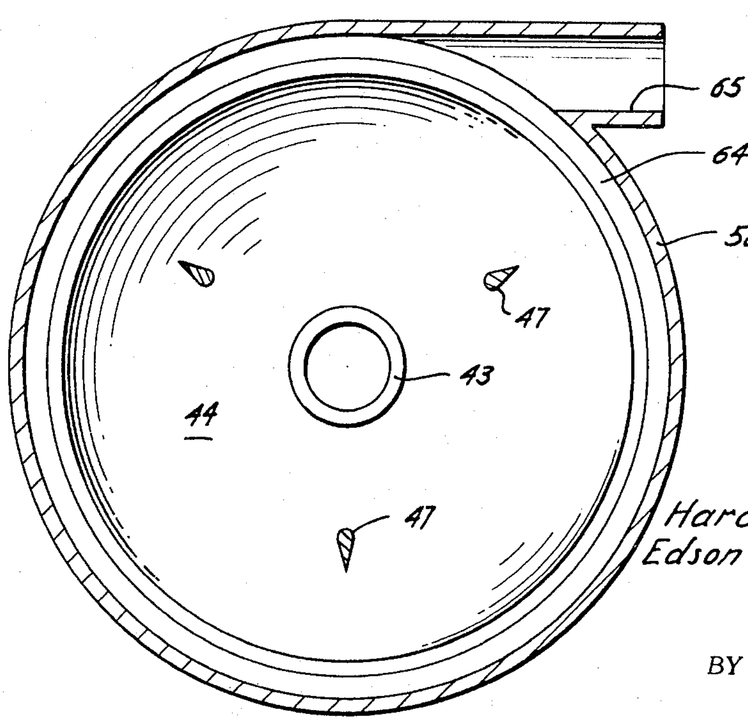

Fig. 4

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Fig. 5

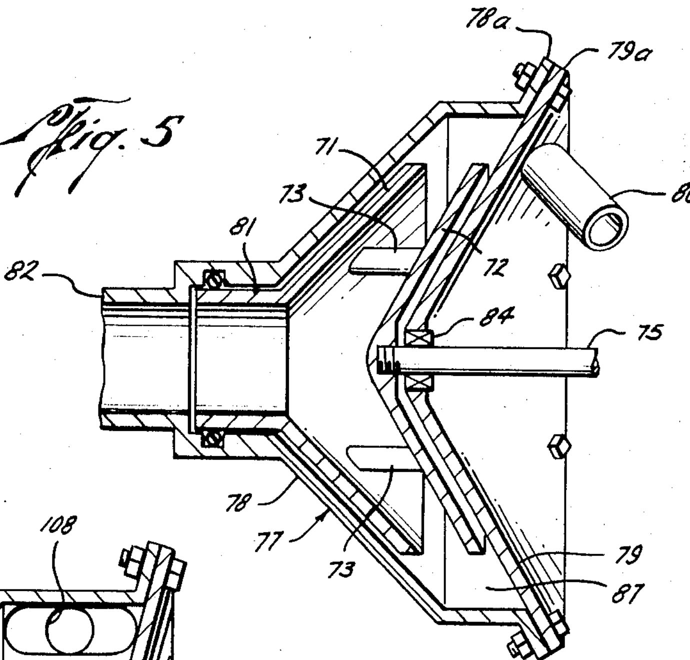


Fig. 6

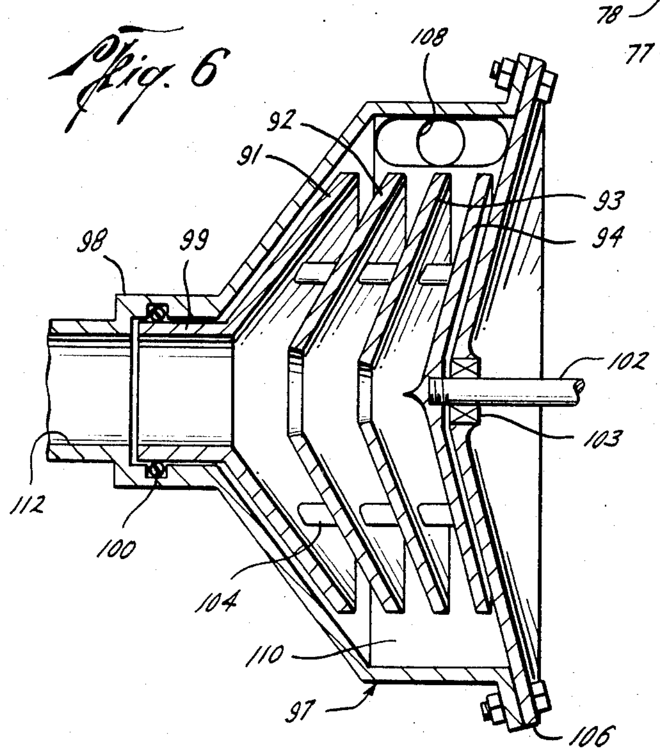
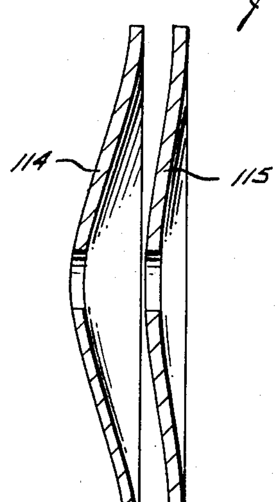


Fig. 7



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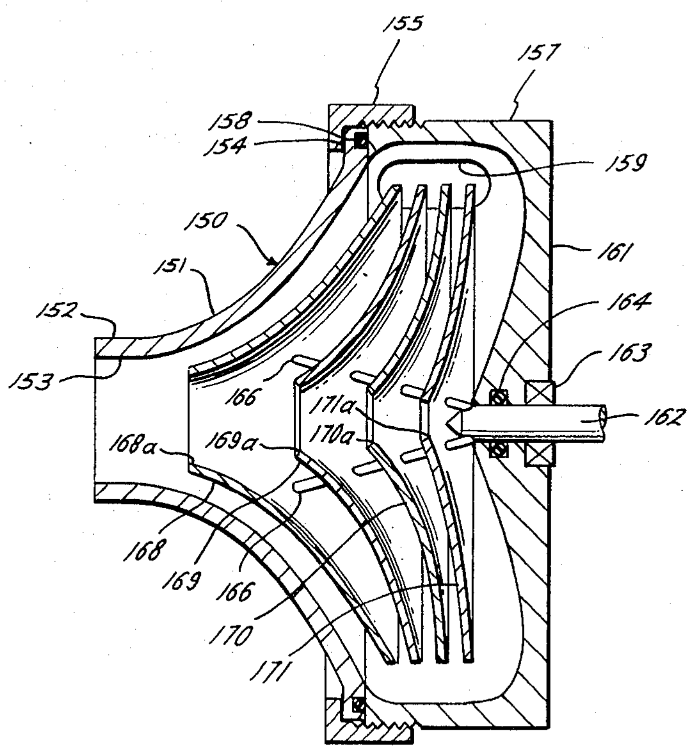

Fig. 8

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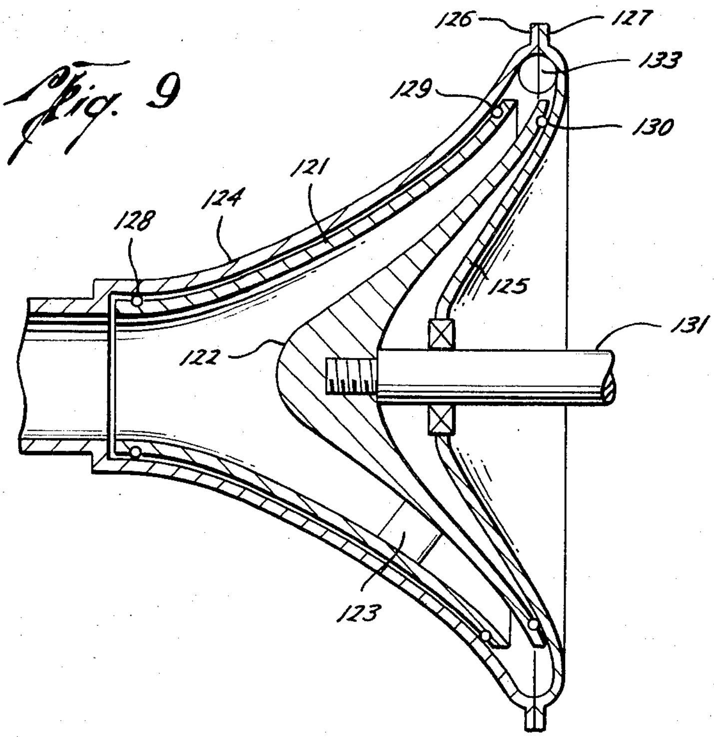

Fig. 9

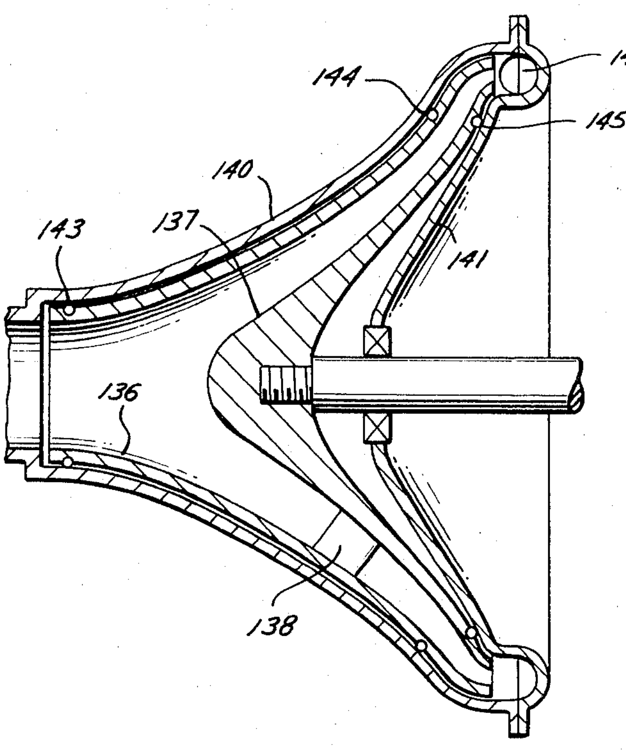

Fig. 10

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PUMPS CAPABLE OF USE AS HEART PUMPS AND BLOOD PUMPS

This application is a continuation-in-part of application Ser. No. 204,980, filed Dec. 6, 1971, now abandoned which was a continuation-in-part of application Ser. No. 886,137, filed Dec. 18, 1969, now U.S. Pat. No. 3,647,324, which in turn is a continuation-in-part of application Ser. No. 678,265, filed Oct. 26, 1967, now U.S. Pat. No. 3,487,784.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The field of the invention is the field relating to pumping apparatuses, particularly to apparatus useful for pumping blood of a living person, or of a living animal, to replace one or more pumping functions of the human or animal heart in case of disability thereof. The heart replacement may be partial or complete, temporary or permanent. While the pumps provided according to the invention are provided principally for pumping blood, the pumps may be employed in other instances for pumping other materials. The pumping equipment provided by the invention has fluid accelerators or rotators which rotate to impel the fluid circularly at substantially the speed of the rotators. The pumps are adapted for pumping of blood, and other delicate fluid materials, biological and nonbiological in nature, without any pronounced physical effect on the blood or other fluid being pumped. The pumps do not impose sudden pressure changes, impacts, rapid changes in direction of flow, in order to prevent injury to or destruction of the pumped material and its components.

In the case where blood and similar liquids have been pumped, artificial heart pumps generally have been of the positive displacement type. Because of the relatively delicate nature and structure of blood, it has been found that use of centrifugal pumps invariably results in physical disruption of the blood and at least some of its components. Although a pulsating movement of blood through the body may not be necessary to sustain life, the prior art has not afforded a solution to the problems involved in utilization of centrifugal pumps for pumping blood, since at least partial destruction of blood has always resulted when centrifugal pumps were used. This invention solves these problems, by providing rotative pumping means for pumping blood or other delicate fluids, which produce minimum levels of shear and tubulence thus limiting any significant destruction of the fluid and its components resulting from the pumping.

2. Summary of the Invention

The invention is of rotative pumps which are suitable for use as heart pumps, blood pumps, and as pumps to pump all types of natural or artificial biological fluids in connection with the maintenance of life and/or biological functions in a human body, animal body, or any other pumping function. The pumps can be used to replace or assist the pumping functions of the heart in vivo or ex vivo. The pumps can be used to pump biological fluids in vitro or in any in vivo, ex vivo, and in vitro combination. The pumps may also be used to pump natural or artificial biological fluids as well as nonbiological fluids. The nonbiological fluids so pumped may be pumped in connection with biological or nonbiological activities, functions, and/or applications.

The pumps according to the invention are rotative pumps having rotators through passages of which the fluid flows outwardly from the axis of the rotator. The rotating rotator surfaces cause the fluid, introduced at or near the rotator axis, to move substantially circularly around the rotator axis at continuously increasing speed as the fluid moves outward toward the rotator periphery. The fluid circulates substantially with the rotator at relatively constant rotational speeds (revolutions per minute) as it moves outwardly, so that its linear speed (distance/time) continuously increases as the fluid moves outwardly in continuously enlarging circular paths. The fluid moves circularly at approximately the angular velocity of the rotator, and this velocity increases as the radial distance from the axis increases. In order that the volume flow remains approximately constant past all radial distances from the fluid inlet to the rotator periphery, the rotator passages (spacing between rotators) decrease in size as the inverse function of the radial distance from the rotator axis. This prevents effects on the fluid such as cavitation, pressurization, depressurization, and the like, from occuring inside the pumps, thereby preventing shock and damage to the fluid being pumped.

The pumps may be used in pumping blood for circulation through the body passages, veins, arteries, etc., of a living person or animal, or for pumping blood through artificial kidneys and lungs of a person or animal. The pumps are adaptable for use disposed within a body cavity, as replacements for any or all of the pumping functions of the heart. The pumps herein provided may also be used externally of the body for pumping blood into the body of a person or animal. The pumps are adapted to pump without producing severe pressure changes, physical impacts, and the like, so that none of the blood or other fluid components are subjected to treatment which will destroy them for use. The pumps do not require the use of valves, such as those of the heart, but valves may be provided if desired particularly in heart assist-type usage.

The punps are useful in both biological and nonbiological applications. The pumps could, for example, be used to propel a motorboat, the pumps being very quiet and of low turbulence, in centrifuging apparatus, as infusion pumps, as suction pumps (for chest tubes, for example), as aspiration devices (to suction out blood from the operative field in an autraumatic fashion so that the blood might be reused in order to save on blood transfusions, etc.) to pump water from boats, for fountain sprays and garden waterfalls, for pumping slurries such as sewage, and for many other uses including but not restricted to uses where gentle handling of the fluid may be desired.

BRIEF DESCRIPTIONS OF THE DRAWINGS

FIGS. 1–2 are vertical cross sectional views of a pump of preferred form according to the invention, FIG. 1 being taken along the axes of rotation of the pump rotators, and FIG. 2 being taken transverse thereto.

FIGS. 3–4 are cross sectional views of a pump of modified form according to the invention, FIG. 3 being taken along the axes of rotation of the pump rotators, and FIG. 4 being taken along a spherical surface between the rotators.

FIGS. 5–6 are similar to FIGS. 1 and 3, and show additional modified embodiments of apparatuses according to the invention.

FIG. 7 is a cross sectional view of an additional form of rotator useful in connection with the invention.

FIGS. 8–10 are similar to FIG. 1, and show additional modified embodiments of apparatus according to the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The pumps will be described with blood as the fluid being pumped, since that is the primary purpose for which the pumps according to the invention have been developed, but it is to be understood that the pumps will be useful for all of the uses and purposes mentioned in the disclosure, and the description may be applied to such uses and purposes.

Blood is a complex and delicate fluid. It is essentially made up of plasma, a pale yellow liquid containing microscopic materials and the "formed elements" which include the red corpuscles (erythrocytes), white corpuscles (leukocytes), and platelets (thrombocytes). These and the other constituents of blood, as well as the nature of suspension of these materials in blood, are fairly readily affected by the manner in which blood is physically handled or treated. Blood subjected to mechanical shear, to impact, to depressurization, or other forces, may be seriously damaged. In addition the balance between the blood constituents may readily be affected. Commencement of deterioration may result from physical mishandling of blood. Blood which has been damaged may be unfit for use.

The heart propels or pumps blood through the body in a circulating, cyclic, fashion. The blood passes repeatedly through the heart. A pump for replacing one or more pumping functions of the heart should therefore be capable of repeatedly pumping the same blood, time and time again, without damaging the blood, at least not more than to the extent where the body can function to repair or replace the blood components and eliminate damaged and waste materials therefrom.

Blood also contains dissolved and chemically combined gases, which may be seriously affected by improper physical handling of the blood. It has, for example, been established that subjecting blood to negative or sub-atmospheric pressures of, say, minus 300 millimeters of mercury, is detrimental not only to the blood cells, which may rupture, but to the body due to the release of dissolved gases from solution, even when the reduced pressures are only temporary.

The blood pressure is the pressure of the blood on the walls of the arteries, and is dependent on the energy of the heart action, the elasticity of the walls of the arteries the peripheral resistance in the capillaries, and the volume and viscosity of the blood. The maximum pressure occurs at the time of the systole of the left ventricle of the heart and is termed maximum or systolic pressure. The normal systolic pressure may be from about 80 millimeters of mercury (mm. Hg) to about 150 mm. Hg. the pressure ordinarily increasing with increasing age. Pressures somewhat outside this range are not uncommon. The minimum pressure is felt at the diastole of the ventricle and is termed minimum or diastolic pressure. The diastolic pressure is usually about 30 to 50 mm. Hg lower than the systolic pressure.

The preferred embodiments of the invention shown and described have in common that the blood or other fluid is handled gently, without shear, shock, vibration, impact, severe pressure or temperature change, or any other condition or treatment which would unduly damage the blood or other fluid. Essentially nonturbulent flow is maintained through the pumps, and the pumped fluid is accelerated gradually and smoothly.

The pumping action obtained may be described as radially increasing pressure gradient pumping, or in some cases more specifically as constrained force-vortex radially increasing pressure gradient pumping. In centrifugal pumps, the fluid acted on by the vanes of the impeller is positively driven or thrown outwardly (radially) by the vane rotation. The fluid as it moves from the vanes to the ring-shaped volute space beyond the tips of the vanes is reduced in velocity, and as the velocity decreases the pressure increases according to Bernoulli's theorum. Handling of many delicate fluids, such as blood, in this fashion would destroy them for use.

On the other hand, in the pumps provided according to this invention, the pumped fluid is not driven or thrust outwardly but instead is constrained to circulate in the pumping chamber at increasing speeds as it moves farther and farther from the center. At the outer periphery of the accelerator or rotator, the speed of the fluid is maximum.

The action of the fluid in the pumps may be clarified by analogy to a glass of water turning about its vertical axis without sideways motion or wobble. Because of its contact with the sides and the inherent potential shear force of the water in the glass, the water will rotate in the form of a force-vortex, without much slip or shear between radially adjacent particles of water, and the water radially away from the center of rotation will be moving faster than water nearer the center. If water is introduced through a tube at the axis of the glass and water is removed through one or more holes through the side of the glass and the water in the glass is constrained by capping off the top of the glass, water will be pumped by the rotation of the glass. In the pumps afforded by this invention, while rotators are provided, in a number of different forms, the rotators are designed such that they act to increase the swirling speed of the liquid passing through the pump, but do not act to drive or throw the liquid toward the periphery or volute of the pump chamber, but instead only increase the rotational speed of the liquid. As the rotative speed of the liquid is increased, it achieves a higher "orbit" about the center of the accelerator and moves toward the periphery of the chamber.

Referring first to FIGS. 1–2 of the drawings, the pump impeller **15** is comprised of a pair of non-parallel rotators **16, 17,** disposed within housing **19** having opposite side walls **20, 21** which are parallel with but spaced from the rotators **16, 17,** respectively. The housing continues radially outwardly to form around the outer edges of the rotators an annular chamber **23.** Wall **21** is secured around its edges by screws **21**a.

A tubular shaft **24** rotatively disposed through O-ring **25** carries the rotators **16, 17.** Tubular shaft **24** has opposite circular openings **27, 28** providing for passage of fluid incoming through the tubular shaft to the space between the rotators. Housing **19** has a tubular concentric nipple formation **29,** O-ring seal **25** being disposed in suitable ring grooves at the outside of tubular shaft **24** and the inside of nipple **29**.

Housing **19** has a tangential outlet **31** from space **23**. The rotators **16, 17**, together with tubular shaft **24**, are driven in rotation by a drive shaft **33** journaled through bearing **34** in the wall of housing **19**. Rotation of tubular shaft **24** in a clockwise direction as shown in FIG. **2** causes rotation of blood or other fluid passing inwardly through inlet pipe or conduit **37** which is sealed to tubular shaft **24** by O-ring **38** disposed in suitable ring grooves inside of tubular shaft **24** and around the exterior of conduit **37**.

The blood, or other fluids to be pumped are passed in through conduit **37** from which the fluid passes into the interior of tubular shaft **24**, then radially outwardly through circular openings **27, 28** in the sides of tubular shaft **24**. The fluid is propelled in rotation by rotation of shaft **24** and by rotation of the two spaced rotators **16, 17**. The rotational velocity of the fluid increases as the radial movement of the fluid outwardly progresses. In other words, fluid rotating at the outer edges of rotators **16, 17** is in faster rotation than is fluid rotating at the inner edges of the rotators. The shapes of rotators **16, 17** are such that the outward fluid flow volume is constant from the inner edges of the rotators to the outer peripheries of the rotators. The rotators are closer together at their peripheries such that the volume of outwardly flowing fluid per units of time at the periphery is the same as the volume of outwardly flowing fluid per unit of time at any circle inward of the rotator peripheries.

In the drawings, the equipment shown is schematic and not to scale, the outward convergence of the rotators actually being considerably greater than shown, with the rotators being closer together at their outer edges or peripheries, and with the flow as described in the preceeding paragraph.

As will be apparent, rotation of the rotators in a clockwise direction, as depicted in FIG. **2**, causes the fluid to rotate in constantly increasing circular paths from shaft **24** to the space **23** around the outer edges of the rotators from which the fluid exits from tangential outlet **31**.

Referring now to FIGS. **3** and **4** of the drawings, there is shown a pump wherein the rotators are curved, i.e., dish-shaped, the curves of the rotators being such that the spacing therebetween diminishes outwardly so that the outward flow rate at constantly increasing speed is volume-constant. Fluid flows from an inlet conduit **43** into the space between rotators **44, 45**, each of curved shape with closer spacing toward the rotator edges. The rotators terminate at the same plane, toward the right, as the rotators are shown in FIG. **3**. The rotators are connected by plural connector rods **47** of streamline shape as shown in FIG. **4**. The rotators are driven in rotation, clockwise as shown in FIG. **4**, by drive means connected to shaft **49** which is carried by rotator **45**. The inner edge of rotator **44** is sealed to conduit **43** by O-ring seal **52**. The pump housing is integral with (or sealed with) the inlet conduit **43** at **53**, the housing being referred to by reference numeral **56**. The housing has curved walls **57, 58** which are closely spaced from and are of the same curvatures as rotators **44, 45**, respectively. The rotator edges are sealed to the housing walls by O-ring seals **61, 62**. An annular circulation chamber **64** is provided within the housing beyond the ends of the rotators. An outlet **65** is provided therefrom through which pumped fluid emerges.

The inner face of rotator **45** is provided with a pointed raised formation **67** which serves to smooth flow from conduit **43** to the space between the rotators. Streamline laminar flow is achieved through conduit **43**, by suitable relatively low flow rates therethrough, and the laminar flow is preserved during flow through the space between the rotators, and the rotator rotation is at a speed such that the rotators impel fluids therebetween in laminar-flow rotation, at continuously increasing speeds as the fluids move outwardly between the rotators toward outlet **65**. The two housing parts are connected at bolt flanges **57*a*, 58*a***. A bearing **69** is provided about drive shaft **49** and housing **56** whereby the rotators may be easily driven in rotation in the prescribed manner.

Referring now to FIG. **5** of the drawings, a modified form of pump is shown wherein the rotators are each of hollow frusto-conical form. Rotators **71, 72** are connected by plural connector bars **73** of streamlined form, as shown for bars **47** in FIG. **4**, so that the two rotators are driven in rotation together by rotational energies provided through shaft **75** from a suitable drive means (not shown). The housing **77** is conformingly shaped, with angular walls **78, 79** of conical shape corresponding to the angles of the respective rotators **71, 72**. Rotator **71** has a nipple-shaped end **81** which is fitted within an outwardly upset opening of the housing adjacent the end of inlet conduit **82** which is formed integrally with the housing. The housing parts are joined at bolting flanges **78*a*, 79*a***.

Bearing **84** is disposed around shaft **75** to reduce friction of rotation. An angular outlet **86** is provided from the housing adjacent space **87** disposed annularly beyond the rotator edges. The conical angles of the rotator surfaces, facing one another, are such that the space is reduced outwardly from the rotator centers such that, at least approximately, the volume movement of fluid through the pump is constant at each radial extent of the rotators.

In FIG. **6**, the pump shown has plural rotators **91–94**, conical and at different angles, so that the rotators are convergent toward their peripheries. Housing **97** is shaped to conform with the shapes of the outer rotators, and has entrance upset **98** to receive rotator **91** nipple **99** sealed by O-ring **100**. Shaft **102** is journaled for rotation through bearing **103**. The rotators are joined by bars **104**. The housing parts are connected at flange connection **106**. Housing **97** has tangential fluid outlet **108** from annular circulation space **110**.

In the FIG. **6** embodiment of apparatus, the inner edges of rotators **92, 93** are flared toward the inlet **112**, such that approximately the same volume of fluid will enter from the inlet to the three spaces between rotators.

Referring to FIG. **7**, there is shown a rotator arrangement wherein the pair of rotators **114, 115** are double curved between their centers and peripheries, the rotators being convergent as before to achieve uniform volume flow at all radial extents of the rotators.

Referring to FIG. **8**, there is shown a pump **150** the design of which eliminates the use of seals between the rotators and housing. The housing consists of two parts. Housing part **151** is flaringly enlarged from end **152** around fluid inlet **153** and has a flat surface **154** around its outer edge to receive a ring-shaped clamp nut **155** thereagainst. Nut **155** extends beyond the end of the housing and is internally threaded. Housing part **157** is outwardly cylindrical and has threads at its open end onto which nut **155** is screwed to connect housing parts **151, 157** together. A seal **158** is disposed in a groove around the annular end of housing part **151** to make the connection leakproof.

A tangential outlet port **159** is provided from the sidewall of housing part **157**. At the center of the closed end **161** of housing part **157**, an opening is provided to receive shaft **162**, journaled in bearing **163**, and surrounded by seal **164**, the bearing and seal are disposed in annular enlargements around the shaft opening.

Endwall **161** is inwardly thickened toward its center. The inner end of shaft **162** is of conical shape, and a plurality, preferably three, small-diameter rods **166** depend angularly from the shaft end at equal angles and equally spaced. A plurality of accelerators of rotators **168–171** of different flared curvatures are supported by the rods **166**. The rotators **168–171** have holes therethrough to receive the rods **166**, rotator **168** being positioned at the ends of the rods, and rotators **169–171** being spaced between rotator **168** and the end of shaft **162**. The rotators are fixed to the rods by press-fitting, or by any other suitable means.

The rotators **168–171** have circular center openings **168*a*–171*a*** of sequentially smaller size. The spacing between the centers of rotators **168, 169** is larger than the spacing between rotators **169, 170**, which is larger than the spacing between rotators **170, 171**. Rotator **168** is spaced from the inside of the flared wall of housing part **151**, and rotator **171** is spaced from the flared inside surface of end wall **161** of housing part **157**.

The between-the-rotator spacings decrease outwardly as in the other embodiments. However, the spacings between the walls of the housing and end rotators, rotators **168** and **171**, increase outwardly. The reason for this is that, because the housing walls do not rotate, and because the angular rotator and fluid speeds increase outwardly, the shear on the fluid would increase outwardly if the end spacings were uniform or decreased outwardly. Therefore, in order to avoid increased shear on the fluid as it circulates outwardly to the rotator peripheries, the end rotator-housing spacings are increased outwardly.

As fluid flows in through inlet **153**, the fluid is reduced in volume as it moves toward the right, as shown in FIG. **8**. The rotator center openings **168*a*–171*a*** are sized to receive the remaining flow at later rotators after partial flow has been diverted by earlier rotators. The unequal inner periphery spacings of the rotators are required by the more sharply flared shapes of earlier rotators as compared with later rotators.

The rotators **121, 122**, of FIG. **9** are joined by plural circularly spaced bars **123**, and are of flaring curved shapes toward their outer ends. The housing parts **124, 125** are joined at bolting flanges **126, 127**. O-ring seals are provided at **128, 129, 130**. Rotator **122** is mounted on the end of rotating shaft **131**, exterior drive means being provided therefor. The pumped fluid exits from between the rotators to a space radially outward of the rotator edges to exit through tangential port **133**.

In FIG. **10**, the pump structure is similar to that shown in FIG. **9**. The pump has rotators **136, 137** connected by bars **138**, as housing made up of parts **140, 141**, seals **143–145**, and outlet port **146**. The fluid exiting from between the rotators exits to a space beyond the rotator edges in an axial direction.

It will be seen that the blood or other fluid passing through the pumps is not submitted to any substantial agitation by the rotation of the rotators, of whichever form, or by any other portion of the pump apparatus. There are no sudden changes in direction of the flow through the pump, all joints between surfaces being smooth and all surfaces over which the fluid flows being smooth.

The spacings between the outer peripheral edges of the rotators may be very close, i.e., a few thousandths of an inch, or may be larger. Inwardly of the rotator outer edges, the spacings become increasingly larger. Close peripheral spacings do not cause unacceptable trauma to blood but do enable the pump to work efficiently. The efficiency of the pump is directly related to the transfer efficiency of the rotators which is a function of the rotator spacing. There exists an optimum spacing for each set of rotators. Therefore, by using the "optimum" spacing, it is possible to optimize the pump efficiency. However, if the close spacings are maintained over a considerable radial extent, then excessive trauma to blood does occur. However, the majority of the spacing effect on efficiency takes place at the largest radii. Thus close spacing need only be maintained at the periphery. Therefore, the rotators can be made with the continuously outwardly decreasing spacings as herein described and thus low traumaticity and high efficiency can be maintained.

It will be realized that pumps may be supplied according to the invention with any number of pumping stages, and may include individual pumping stages of any of the types mentioned herein in any combination.

In each of the pumps shown in FIGS. **1–6**, and pumps wherein use is made of rotators (or accelerators) of the different forms shown in FIGS. **7–8**, it will be noted that the rotators are designed to avoid turbulence and to avoid rapid pressuring and depressuring of the blood or other fluid being pumped, and also to avoid any physical grinding or abrasive action upon the fluid. As has been made clear, these rotator designs are made in this manner in order that blood or other delicate liquids or gases being pumped, some containing solids in suspension, will not suffer detriment and will not be destroyed by the pumping operation.

The convergence of the rotators, with diminution of the flow space therebetween outwardly, prevents cavitation (dissolved gases coming out of solution to form bubbles because of the pressure reduction within the pumps), which would adversely affect pumping efficiencies and cause damage to certain fluids, such as blood. The convergence of the rotators may be such that the flow rate either somewhat increases outwardly or somewhat decreases outwardly, with corresponding pressure changes on the fluid being pumped. In the outer annular flow spaces between the rotators mximum fluid velocity is maintained, so that conversion of velocity to pressure occurs at the outer pump housing and as fluid enters the pump outlet.

In contrast to centrifugal pumps, the revolutions per minute of the rotators employed with the pumps herein shown and described are designed to be kept minimal. The several rotator designs presented are each of a form adapted to progressively increase the circular fluid velocities as the rotator turns and as the fluid advances toward the periphery of the rotator. In each pump presented, the annular fluid circulation space is almost entirely unobstructed and regular so that fluid can circulate therein without turbulence or baffle effects. The connecting struts, which are kept as small as possible, provide the only exception to this. These struts may also be kept as close to the center of rotation as possible to minimize their velocities, as shown in FIG. 8.

As hereinbefore indicated, pumps may be made according to the invention incorporating features from one or more of the preferred embodiments shown and described herein, any particular feature not being confined to use only with the other features in connection with which it is herein shown and described.

The pumps and their parts may be constructed of any materials compatible with their intended use, including metals, mineral materials, plastics, rubbers, wood, or other suitable materials. When blood is to be pumped, consideration must be given to biological compatibility so that trauma to the blood will not result. Low temperature isotropic carbon and certain polymers or rubbers have been successfully used in contact with blood, without traumatic effects, and may be used in construction of the pumps for blood pumping adaptations. Non-corrosive metals and alloys may be used in the pumps where required.

The housings and rotators may be constructed of suitable material so that the housing may be rigid, semi-rigid, or elastic in whole or in part. The non-rigid constructions can be used for imparting pulse configurations to blood in heart simulation pumps.

While the rotators shown herein may in some cases perform better when rotated in one direction, it should be understood that they may be rotated in either direction, or may vary in rotational velocity and direction, i.e., reversed, without other modification of the pumps. Each of the rotators presents surfaces to the fluid being pumped, to cause accelerating circular fluid motion in the pumping chamber. In some cases, the surfaces are parallel to the fluid flow; in other cases parallel and non-parallel surfaces are provided. Each of these surfaces, of whatever form, will accelerate the fluid regardless of the direction of rotation of the rotator. Each rotator should be rotated at a speed such that essentially no fluid turbulence occurs, and differences in the rotator designs affects the maximum speed at which a particular rotator may be rotated. The physical and flow properties of the fluid pumped will, of course, also affect the maximum speeds of rotation at which the rotators may be operated without turbulence and other objectionable effects, such as cavitation, vapor binding, and the like. It is, therefore, not possible to set forth exact rotational speed ranges for the rotators. But, the speeds of rotation will usually be substantially lower than those of traditional centrifugal pumps and blowers, wherein turbulence always occurs as the impellers thrust the fluid radially outwardly against the periphery of the pumping chamber, and those of the aforementioned multiple disc pumps and compressors. To the end of achieving reduced rotator speeds, pumps provided according to this invention may be of larger size than other pumps, for the same pumping capacity. As internally placed heart pumps, the pumps may be as large as four inches in diameter, and, with removal of a lung, for example, even larger.

According to the precepts of this invention, the forms of the rotators may vary considerably. For example, the rotators may be constructed entirely or partly of porous or perforate materials, i.e., the rotators which accelerate the fluid circularly may be made of screen, of perforate plates or sheets, of spaced rods, or the like, and will still ably perform their fluid accelerating function. They may also be constructed out of solid or non-porous materials. Rotators may be of axially extended form, so that the fluid is accelerated axially or axially and radially. Designs of this nature would extend the flowpath from inlet to outlet so that acceleration would be at a slower rate. The rotators of FIGS. 1–7 and 8–10 are made to become closer together, instead of farther apart, toward the periphery of the rotator. In each of the pumps shown and/or described, one or more tangential outlets could be provided, disposed in the direction of fluid flow inside the peripheral wall of the pump. In multi-stage pumps, the several rotators, which may be alike or unlike, may be driven at different rotational speeds. The axes of multi-stage rotators may be offset and in other positions out of alignment.

While preferred embodiments of apparatus according to the invention have been shown and described, many modifications thereof may be made by a person skilled in the art without departing from the spirit of the invention, and it is intended to protect by Letters Patent all forms of the invention falling within the scope of the following claims.

What is claimed is:

1. A method of pumping blood which is subject to damage under impact and shear, said method comprising rotating an impeller having a pair of axially spaced smooth discs that define a constant annular cross sectional vaneless pumping chamber therebetween, providing one disc with a central opening communicating with the inner portion of said annular pumping chamber, subjecting the blood to centrifugal action by engagement with the smooth walls of the rotating discs that define the pumping chamber, increasing the outward movement of blood under laminar flow conditions without appreciable turbulance to the outer peripheries of the discs and collecting the discharged laminar flow of said blood from said pumping chamber in an annular unobstructed chamber about said discs without subjecting the blood to impact and/or shear.

2. A method according to claim 1 wherein the discs converge outward of their centers.

3. A method according to claim 1 wherein the outer portion of the pumping chamber is spaced axially of the inner portion of the pumping chamber.

4. A method of pumping natural and artificial fluids which are subject to damage under impact and shear, said method comprising rotating an impeller having a pair of axially spaced smooth discs that define a constant annular cross sectional vaneless pumping chamber therebetween, providing one disc with a central opening communicating with the inner portion of said annular pumping chamber, subjecting the fluid to centrifugal action by engagement with the smooth walls of the rotating discs that define the pumping chamber, increasing the outward movement of fluid under laminar flow conditions without appreciable turbulance to the outer peripheries of the discs and collecting the discharged laminar flow of said fluid from said pumping chamber in an annular unobstructed fluid from said pumping chamber in an annular unobstructed chamber about said discs without subjecting the fluid to impact and/or shear.

5. A method according to claim **4** wherein the discs converge outward of their centers.

6. A method according to claim **4** wherein the outer portion of the pumping chamber is spaced axially of the inner portion of the pumping chamber.

7. A method of pumping blood which is subject to damage under impact and shear, said method comprising rotating an impeller having a plurality of axially spaced smooth discs that define constant annular cross sectional vaneless pumping chambers therebetween, providing all but the axially rearmost of the discs with central openings communicating with the inner portions of said annular pumping chambers, subjecting the blood to centrifugal action by engagement with the smooth walls of the rotating discs that define the pumping chambers, increasing the outward movement of blood under laminar flow conditions without appreciable turbulance to the outer peripheries of the discs and collecting the discharged laminar flow of said blood from said pumping chambers in an annular unobstructed chamber about said discs without subjecting the blood to impact and/or shear.

8. A method according to claim **7** wherein the discs converge outward of their centers.

9. A method according to claim **7** wherein the outer portion of each pumping chamber is spaced axially of its inner portion.

10. A method of pumping natural and artificial fluids which are subject to damage under impact and shear, said method comprising rotating an impeller having a plurality of axially spaced smooth discs that define constant annular cross sectional vaneless pumping chambers therebetween, providing all but the axially rearmost of the discs with central openings communicating with the inner portions of said annular pumping chambers, subjecting the fluid to centrifugal action by engagement with the smooth walls of the rotating discs that define the pumping chambers, increasing the outward movement of fluid under laminar flow conditions without appreciable turbulance to the outer peripheries of the discs and collecting the discharged laminar flow of said fluid from said pumping chambers in an annular unobstructed chamber about said discs withhout subjecting the fluid to impact and/or shear.

11. A method according to claim **10** wherein the discs converge outward of their centers.

12. A method according to claim **10** wherein the outer portion of each pumping chamber is spaced axially of its inner portion.

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