(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
7 September 2012 (07.09.2012)

WIPO | PCT

(10) International Publication Number
WO 2012/118705 A2

(51) International Patent Classification:
A61M 1/26 (2006.01) *B01D 37/00* (2006.01)
A61M 1/16 (2006.01)

(21) International Application Number:
PCT/US2012/026499

(22) International Filing Date:
24 February 2012 (24.02.2012)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
13/036,814 28 February 2011 (28.02.2011) US

(71) Applicant *(for all designated States except US)*: **FENWAL, INC.** [US/US]; Three Corporate Drive, Lake Zurich, IL 60047 (US).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **WEGENER, Christopher, J.** [US/US]; 601 Buckingham Place, Libertyville, IL 60048 (US). **BOGGS, Daniel, R.** [US/US]; 1722 River Birch Way, Libertyville, IL 60048 (US). **MIN, Kyungyoon** [KR/US]; 23369 Providence Drive, Kildeer, IL 60047 (US). **MATHEW, Prakash** [US/US]; S87W28186 Lookout Lane, Mukwonago, WI 53149 (US). **WEASLER, Marc, N.** [US/US]; 5861 S. 18th Avenue, West Bend, WI 53095 (US). **KUSTERS, Benjamin, E.** [US/US]; 3410 Foxwood Road, Racine, WI 53405 (US).

(74) Agents: **MCFARRON, Gary W.** et al.; Cook Alex Ltd., 200 West Adams Street, Suite 2850, Chicago, IL 60606 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD,

[Continued on next page]

(54) Title: SYSTEMS AND METHODS FOR SINGLE NEEDLE CONTINUOUS BLOOD PROCESSING

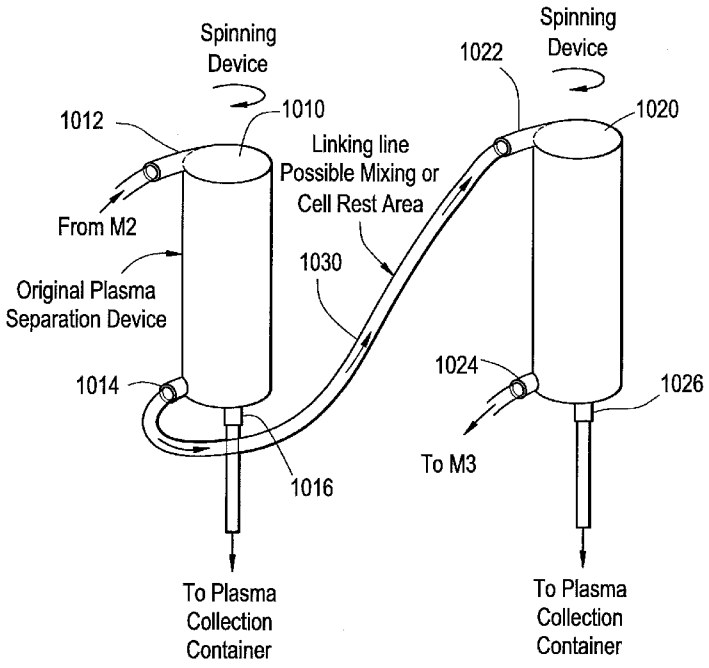


FIG. 10

(57) Abstract: Certain examples describe systems and methods for processing blood. An example method includes receiving blood extracted from a blood source connected to a blood collection machine. The example method includes processing the blood using a filtration or separation device to remove at least a portion of a targeted component included in the blood to separate the targeted component removed from a non-targeted component. The non-targeted component may then be re-processed using either the same or a different filtration or separation device to remove an additional amount of the targeted component.

WO 2012/118705 A2

SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

SYSTEMS AND METHODS FOR SINGLE NEEDLE CONTINUOUS BLOOD PROCESSING

Related Application

This application claims the benefit of U.S. patent application Serial No. 13/036,814 filed February 28, 2011, which is hereby incorporated herein by reference.

Technical Field

The present invention relates generally to methods, systems, and apparatus to provide blood processing from a donor or other blood source. More particularly, the present invention relates to methods, systems, and apparatus to provide single needle continuous blood component collection from a donor or other blood source.

Background

By extracting only one or more components (e.g., red blood cells, platelets, and/or plasma) from a donor or other blood source (e.g., a container of stored blood) and returning remaining blood to the donor or other blood source, a blood collection center can extract more of the component(s) from the donor or other blood source than they could if only whole blood were collected.

Summary

In accordance with one aspect of the present disclosure, a blood processing method includes separating blood into one or more targeted blood components, such as plasma or particular cellular components, and one or more non-targeted components, such as cellular components, using a separation device. During a first time period, at least a portion of the targeted component is flowed out of the separation device and the non-targeted component is re-processed to remove additional targeted component using the separation device.

In another aspect of the disclosure, a blood processing system includes first and second separation devices. The first separation device is adapted to receive blood from a blood source and separate a portion of a targeted component from the blood. The second separation device is adapted to receive

non-targeted components remaining after separation by the first separation device and to separate additional targeted component from the non-targeted components.

In yet another and more specific aspect, a blood processing method includes separating blood into targeted and non-targeted components using a first separation device. At least a portion of the cellular components and at least a portion of the targeted component separated from the non-targeted components is flowed out of the first separation device. The non-targeted components are re-processed to remove additional targeted component using a second separation device.

As made clearer below, there are several aspects of the present subject matter which may be embodied separately or together in the methods and systems described and claimed below. These aspects may be employed alone or in combination with other aspects of the subject matter described herein, and the description of these aspects together is not intended to preclude the use of these aspects separately or the claiming of such aspects separately or in different combinations as set forth in the claims appended hereto.

Brief Description of the Drawings

Certain example embodiments of the invention, together with features and the advantages thereof, may best be understood by reference to the following description taken in conjunction with the accompanying drawings, in which like reference numerals identify like elements in the figures, and in which:

FIG. 1 illustrates an example collection apparatus configuration for blood processing.

FIG. 2 illustrates an example draw cycle configuration in a collection-on-return apparatus.

FIG. 3 illustrates an example return cycle configuration in a collection-on-return apparatus.

FIG. 4 depicts an example procedure time reduction as a function of return-phase plasma flow rate and blood flow rate.

FIG. 5 shows an example effect of flow on processing time for both normal and turbo modes given performance according to a concentration polarization model with zero transition time.

FIG. 6 depicts a flow diagram for an example method for plasma collection from a donor.

FIG. 7 shows an example three-port plasma separation filter device.

FIG. 8 shows example modifications to a standard separation device.

FIG. 9 shows example master and slave kits mounted in master and slave instruments.

FIG. 10 illustrates two example plasma separation devices linked in series.

FIG. 11 depicts a flow diagram for an example method for plasma collection from a donor.

FIG. 12 shows an example comparison between membrane limited transport and red cell layer limited transport.

FIG. 13 depicts a combined transport behavior evaluated using both membrane limited transport and red cell layer limited transport.

FIG. 14 illustrates an example graph of transmembrane pressure versus plasma flow rate.

FIG. 15 illustrates an example concentration polarization model formed for red cell layer limited transport.

The foregoing summary, as well as the following detailed description of certain embodiments of the present invention, will be better understood when read in conjunction with the appended drawings. For the purpose of illustrating the invention, certain embodiments are shown in the drawings. It should be understood, however, that the present invention is not limited to the arrangements and instrumentality shown in the attached drawings.

Description of the Illustrated Embodiments

It will be understood that the present invention may be embodied in other specific forms without departing from the spirit thereof. The present examples and embodiments, therefore, are to be considered in all respects as illustrative and not restrictive, and the invention is not to be limited to the details presented herein.

Using a spinning membrane separation device (e.g., a Fenwal Plasmacell-C®, which is described in greater detail in U.S. Patent No. 5,194,145 to Schoendorfer, the disclosure of which is incorporated herein by reference) or other blood filtering or component separation device, a blood component can be collected from blood drawn from a donor or other blood source (including a blood

storage container or reservoir and other non-human sources). The blood from the donor or other blood source is directed into the separation device and processed therein to separate one of the blood components from the other, non-targeted blood component(s). In certain examples (typically single accessor needle systems where blood is alternatively drawn from a source and blood components returned), a first time period is spent drawing blood from a donor or other blood source for collection of the targeted component, and a second time period is spent returning remaining blood component(s) to the donor or other blood source after a targeted component collection draw cycle. In certain examples, rather than the separation device being idle during a return cycle, blood or blood components can be re-circulated or passed again through the separation device on return to collect an additional amount of the targeted component from the blood before the blood remainder is returned to the donor or other blood source.

Collection on return is based on a premise that, during a single needle procedure, blood separated by a spinning membrane separation device (or other blood filtering or component separation device) upon being drawn from a donor or other blood source can be passed through and processed by the same separation device a second time directly before being returned to a donor or other blood source. Double processing by the same separation device allows for continuous collection of the targeted blood component throughout the procedure, rather than allowing the separation device to be unutilized during a return of blood to the donor or other blood source.

Certain examples allow for blood separation and plasma collection using a spinning membrane separation device while drawing and returning blood from a donor or other blood source. That is, high hematocrit blood (e.g., 55-60%) is passed through a single separation device (e.g., a Fenwal Plasmacell-C®) for a second time before being returned to a donor or other blood source during a return stage. In certain examples blood can be passed through a separation device in a forward and/or reverse direction. For example, pump and spinner direction can be reversed to allow blood flow into a bottom (e.g., a red blood cell port) and out of a top (e.g., a whole blood port) of the spinning membrane separation device. In certain examples, a spinning membrane separation device can be positioned upside down in the system for plasma separation and

collection. In certain examples, blood is recirculated through a spinning membrane separation device in its original orientation.

Current practices allow blood separation and plasma collection using a spinning membrane separation device only while drawing blood from a donor or other blood source. An ability to separate blood and collect plasma during the return phases of a procedure is advantageous because overall procedure time is significantly reduced. An ability to pass already concentrated blood from an in-process reservoir back through the spinning membrane separation device or plasma separation or filtration device for a second time before being returned to a donor or other blood source is a unique distinction between certain examples of systems, apparatus, and methods described herein and prior spinning membrane separation device or plasma separation or filtration device separation methods and practices. Prior practices return already concentrated blood straight back to the donor or other blood source from the reservoir without passing the blood through the spinning membrane separation device or plasma separation or filtration device for a second time, and, thus, do not continuously process blood throughout an entire procedure.

In certain examples, variations are based on a location at which blood is brought into the plasma separation or filtration device during return. For example, blood can be removed from the in-process reservoir and separated by entering at the top of and exiting at the bottom of the spinning membrane separation device or plasma separation or filtration device, or in the reverse direction in which blood enters the bottom of the spinning membrane separation device or plasma separation or filtration device and exits through the top. In another example, blood can enter and exit the spinning membrane separation device or plasma separation or filtration device in the same direction as during blood collection.

In certain examples, plasma can be collected using a plasmapheresis device, such as Fenwal's Autopheresis-C® instrument, which may be configured for continuous processing of blood and continuous collection of plasma during draw and return cycles, as well as during transition between cycles, all through a single needle. Thus, plasma can be filtered from blood with an almost zero transition time, as opposed to current techniques involving a single device that cycles and includes a transition time to prepare the device and the blood between each cycle.

Certain examples provide a method for plasma collection from a donor or other blood source. The method includes receiving blood from a donor or other blood source and filtering or separating the received blood using a first separation filter or plasma separation device. The method includes collecting, during a first time period, plasma separated from remaining blood components via the separation filter or plasma separation device. The method includes re-filtering the remaining blood components through the first separation filter or plasma separation device. The method includes collecting, during a second time period, plasma separated from remaining blood components via the separation filter or plasma separation device. The method includes routing remaining blood components from the separation filter or plasma separation device.

Certain examples provide a plasma collection system including a first plasma filtration or separation device to filter or separate plasma from blood drawn from a donor or other blood source and a second plasma filtration or separation device to filter or separate plasma from blood drawn from a donor or other blood source. The first plasma filtration or separation device is adapted to receive blood from a donor or other blood source and to filter or separate a portion of plasma from the blood. The second plasma filtration or separation device is adapted to receive blood remaining after filtration by the first plasma filtration or separation device and to filter or separate additional plasma from the blood remaining after filtration by the first plasma filtration or separation device.

Certain examples provide a method for increasing plasma extracted from blood. The method includes receiving blood extracted from a donor or other blood source connected to a blood collection machine. The method includes filtering or separating the blood using a filtration or separation device to remove at least a portion of plasma included in the blood to separate the plasma removed from remaining blood. The method includes routing the plasma removed for collection. The method includes re-filtering or re-separating the remaining blood using the filtration or separation device (or one or more connected filtration or separation devices) to remove additional plasma from the remaining blood. The method includes routing the additional plasma removed for collection.

FIG. 1 illustrates an example of collection apparatus configuration 100 for a blood separation procedure, such as plasmapheresis. Various aspects of the present disclosure will be described in the context of systems and methods for

separating and collecting plasma (e.g., essentially cell-free plasma) from whole blood. This is for purpose of illustration only, and the systems and methods described herein may be used for any suitable target component of blood. For example, the targeted component may be any other blood component (e.g., white or red blood cells or platelets) or a combination of blood components (e.g., any combination of two or more of white blood cells, red blood cells, platelets, and plasma, such as platelet-rich plasma or cellular blood components alone or with plasma). In these instances, the non-targeted component comprises the other or remaining components of the blood. The example apparatus 100 includes a blood source draw line 1, a blood pump (M2) 2, an anticoagulant (AC) pump (M1) 3, a continuous processing line 4, a separation device (e.g., Plasmacell-C®) 5, a red cell pump (M3) 6, an in process line 7, an in process reservoir 8, a return processing line 9, a blood source return line 10, binary clamps 11-12, a plasma line 13, and a plasma collection container 14. The system 100 is explained in further detail below in conjunction with a draw cycle configuration 200 and return cycle configuration 300.

FIG. 2 illustrates an example draw cycle configuration of a collection on return apparatus 200. The example apparatus 200 includes a blood source draw line 1, a blood pump (M2) 2, an AC pump (M1) 3, a continuous processing line 4, a separation device 5, a red cell pump (M3) 6, an in process line 7, an in process reservoir 8, a return processing line 9, a blood source return line 10, binary clamps 11-12, a plasma line 13, and a plasma collection container 14.

During a draw cycle 200, depicted in FIG. 2, as indicated by arrows 202, 204, 206, and 208, blood is continuously drawn into the system from a donor or other blood source by the M2 blood pump 2 (as indicated by arrow 210) via the blood source draw line 1. The blood source draw line 1 is in an open position of the binary clamp 11 to allow blood flow while the return processing line 9 is in a closed position of the binary clamp 11 to prevent blood flow. As indicated by the flow of arrows 210, 212, 214, and 216, the M2 blood pump 2 passes the whole blood (WB) through the continuous processing line 4 into the top port of the separation device 5. Within the separation device 5, the WB is separated by a spinning membrane filtration device or other plasma separation means. Plasma is collected in the plasma collection container 14 via the plasma line 13 and, at 218, high hematocrit (HCT) blood (e.g., approximately 58% HCT) is pulled out of the

separation device 5 by the M3 red cell pump 6 (as indicated by arrow 220) and, as indicated by arrows 222, 224, and 226, placed into the in process reservoir 8 via the in process line 7. The in process line 7 is in the open position of the binary clamp 12 to allow blood flow while the blood source return line 10 is in the closed position of the binary clamp 12 to prevent blood flow. The draw cycle continues until the in process reservoir 8 is filled (or at least partially filled) with high HCT blood. Once the in process reservoir 8 is filled (or at least partially filled), both binary clamps and/or other open/closing devices 11-12 are to instantaneously (or at least substantially instantaneously given some system delay) reverse their opened and closed positions to divert blood flow, allowing the system 200 to transition to a return cycle.

FIG. 3 illustrates an example return cycle configuration in a collection on return apparatus 300. The example apparatus 300 includes a blood source draw line 1, a blood pump (M2) 2, an AC pump (M1) 3, a continuous processing line 4, a separation device 5, a red cell pump (M3) 6, an in process line 7, an in process reservoir 8, a return processing line 9, a blood source return line 10, binary clamps 11-12, a plasma line 13, and a plasma collection container 14.

During a return cycle 300, depicted in the example of FIG. 3, high HCT blood is continuously (or at least substantially continuously accounting for some equipment delay) pumped out of the in-process reservoir 8, as indicated by arrows 302, 304, 306, and 308, by the M2 blood pump 2 via the return processing line 9. The return processing line 9 is in the open position of the binary clamp 11 to allow blood flow while the donor draw line 1 is in the closed position of the binary clamp 11 to prevent blood flow. As indicated by arrows 310, 312, 314, and 316, the M2 blood pump 2 passes the high HCT blood through the continuous processing line 4 into the top port of the separation device 5. Within the separation device 5, the high HCT blood is again separated by the spinning membrane filtration device or other plasma separation means. Plasma is collected in the plasma collection container 14 via the plasma line 13 and, as indicated by 318, concentrated red cells (e.g., approximately 68% HCT) are pulled out of the separation device 5 by the M3 red cell pump 6. As indicated by 320, 322, 324, and 326, the M3 red cell pump 6 then passes the concentrated red cells through the blood source return line 10 and directly back to the donor or other blood source. The blood source return line 10 is opened to allow blood flow while the in-process line 7 is closed to

prevent blood flow. The return cycle continues until the in process reservoir 8 is emptied (or at least partially emptied). Once the in process reservoir 8 is emptied (or at least partially emptied), both binary clamps 11-12 are to instantaneously (or at least substantially instantaneously) reverse their opened and closed positions to divert blood flow, allowing the system 300 to transition to a draw cycle. Transition draw and return cycles continue until the plasma collection target is met. Collecting plasma on both draw and return helps reduce system idle time and speed time of plasma collection from a donor or other blood source. In certain examples, the first collection cycle begins on a draw and the last collection cycle ends on a return to help ensure excess blood does not remain in the system, for example.

In certain examples, by examining processing time and flow rate, a value or benefit of plasma collection on return as well as on draw can be evaluated. For example, a processing time for each draw-return cycle, T_{PC}, is given by

$$T_{PC} = T_{DC} + T_{TC} + T_{RC} \qquad (1)$$

where T_{RC} is a return time, T_{DC} is a draw time, and T_{TC} is a collection-to-return transition time. Initially, ignoring T_{TC} for the example and noting that

$$T_{DC} = \frac{V_R}{Q_{R,IN}} \quad \text{and} \quad T_{RC} = \frac{V_R}{Q_{R,OUT}} \qquad (2),$$

where V_R is a reservoir volume and $Q_{R,IN}$ and $Q_{R,OUT}$ are flow rates into and out of the reservoir, this becomes

$$T_{PC} = V_R\left[\frac{1}{Q_{R,IN}} + \frac{1}{Q_{R,OUT}}\right]. \qquad (3)$$

An RBC flow rate into the reservoir, $Q_{R,IN}$, is given by

$$Q_{R,IN} = Q_I - Q_{PD} \qquad (4)$$

where Q_I and Q_{PD} are the inlet blood and plasma flow rates, respectively, during the draw. Thus,

$$T_{PC} = V_R\left[\frac{1}{Q_I - Q_{PD}} + \frac{1}{Q_{R,OUT}}\right]. \qquad (5)$$

A volume of plasma collected per cycle, V_{PC}, is

$$V_{PC} = Q_{PD}T_{DC} + Q_{PR}T_{RC} = V_R\left[\frac{Q_{PD}}{Q_I - Q_P} + \frac{Q_{PR}}{Q_R}\right]. \qquad (6)$$

A number of cycles, N, used to obtain a target amount of plasma, V_T, is

$$N = \frac{V_T}{V_{PC}} \qquad (7)$$

and a total processing time, T_P, is

$$T_P = NT_{PC} = V_T \frac{T_{PC}}{V_{PC}} . \qquad (8)$$

Combining Equations 5, 6, and 8 and simplifying yields

$$T_P = \frac{V_T}{Q_{PD} + FQ_{PR}}[1 + F] \quad (9)$$

where

$$F = \frac{Q_I - Q_{PD}}{Q_R} . \qquad (10)$$

As shown in Equations 9 and 10, F indicates a ratio of reservoir filling rate to reservoir emptying rate. For a special case of $Q_{PR} = 0$, this becomes

$$T_P = \frac{V_T}{Q_{PD}}[1 + F] . \qquad (11)$$

Since N is not restricted to integer values, Equations 9 and 11 include a reduced contribution in the last fractional cycle.

Combining Equations 6 and 7, a number of cycles is given by

$$N = \frac{V_T}{V_R} \cdot \frac{Q_I - Q_{PD}}{Q_{PD} + FQ_{PR}} . \qquad (12)$$

A total transition time, T_T, is given by

$$T_T = [\text{int}\, N + 1]T_{TC} , \quad (13)$$

where int N is an integer portion of N.

Thus, a total processing time, including transitions, is

$$T_P = \frac{V_T}{Q_{PD} + FQ_{PR}}[1 + F] + [\text{int}\, N + 1]T_T , \qquad (15)$$

where F and N are defined as above.

A potential benefit of filtration during a return phase is illustrated for example draw-phase conditions in FIG. 4. FIG. 4 depicts a procedure time

reduction (e.g., positive values) as a function of return-phase plasma flow rate and blood flow rate, for example. Plasma flow rate during return is expressed as a ratio of milliliters (ml) over minutes (min), for example. Procedure time reduction is expressed in minutes, for example.

In the example of FIG. 4, plasma flow rate on return has an upper bound at a concentration polarization (CP) limit. This upper limit can be estimated using a CP model. FIG. 5 shows an example effect of Q_R on processing time for both normal and high-flow or turbo modes given performance according to the CP model with zero transition time. Also shown are calculated processing times for normal and high-flow modes without collection on return. Results from an example procedure time study are also shown for reference. As shown in the example of FIG. 5, a time savings of about nine minutes is expected with collection on return. Further, as shown in the example of FIG. 5, processing time is relatively insensitive to a return flow rate in a range of 130-150 milliliters per minute.

FIG. 6 depicts an example flow diagram representative of process(es) that may be used with respect to examples described herein. The example process(es) of FIG. 6 may be driven using a processor, a controller and/or any other suitable processing device. Although the example process(es) of FIG. 6 are described with reference to the flow diagram of FIG. 6, other methods of implementing the process(es) of FIG. 6 may be employed. For example, the order of execution of the blocks may be changed, and/or some of the blocks described may be changed, eliminated, sub-divided, or combined. Additionally, any or all of the example process(es) of FIG. 6 may be performed sequentially and/or in parallel and with any blood component being targeted for separation and collection.

FIG. 6 depicts a flow diagram for an example method 600 for plasma collection from a donor. While FIG. 6 illustrates an exemplary method of collecting plasma from a donor using a filtration device, it should be understood that the method is not limited to the processing of blood from a donor using a filtration device, but may include the processing of blood from any blood source and using any suitable plasma separation device. At block 605, blood is drawn into a plasma and/or other blood component collection system from a donor or other blood source using a pump to pull blood along a blood source draw line.

The blood source draw line is placed in the open position with a first binary clamp to allow blood flow while a return processing line is closed using a second binary clamp to prevent blood flow through the return line. At block 610, the whole blood (WB) is pumped into a spinning membrane filtration device or other plasma separation device through a port of the filtration or separation device. At block 615, within the filtration or separation device, the WB is separated by spinning and passing through one or more membrane filters or other plasma separation means. At block 620, plasma is collected in a plasma collection container or reservoir via a plasma line and remaining blood component(s) are pumped into an in process reservoir via an in process line. The in-process line is open to allow blood flow while a blood source return line is closed to prevent blood flow through that line. The draw cycle of blocks 605-620 continues until the in process reservoir is filled (or at least partially filled) with remaining blood.

At block 625, once the in process reservoir is filled (or at least partially filled), the clamp positions are reversed to divert blood flow, allowing the system to transition to a return cycle. At block 630, blood from the in-process reservoir is pumped out of the in process reservoir via the return processing line. The return processing line is open to allow blood flow while the donor draw line is closed to prevent blood flow. The blood is pumped into a port of the filtration or separation device. At block 635, within the filtration or separation device, the blood is again separated by the spinning membrane filtration device or other plasma separation means. At block 640, plasma is collected in the plasma collection container via the plasma line and concentrated red cells are pulled out of the filtration or separation device by a pump and passed through the blood source return line back to the donor or other blood source. The blood source return line is open to allow blood flow while the in process line is closed to prevent blood flow. The return cycle continues until the in process reservoir is emptied (or at least partially emptied). At block 645, once the in process reservoir is emptied (or at least partially emptied), the lines are to reverse their opened and closed positions (e.g., using binary clamps) to divert blood flow, allowing the system to transition to a draw cycle. At block 650, transition draw and return cycles continue until the plasma collection target is met.

Certain examples help increase blood component separation speed using a modular separation filter or device assembly. Currently, plasmapheresis filtration

devices, such as the Autopheresis-C® manufactured by Fenwal, separate plasma from whole blood using filtration technology. The separation speed (e.g., plasma production speed) is limited by a capacity of the filter assembly. Certain examples provide systems and methods to run a plasmapheresis procedure over multiple available instruments. For example, certain examples utilize a plasmapheresis device in conjunction with an identical (or substantially identical) second device (and/or a specialized spinner or separation assembly) to increase separation throughput using a modular filtration or separation assembly running on multiple instruments.

Using a second plasmapheresis or other blood separation device occupies that second device but increases speed of separation of the targeted component from whole blood (e.g., by doubling the plasma separation speed). The modified kit is modularly expandable by just the filter or separation sub-assembly and does not require a whole second identical kit.

Certain examples can be extended from two instruments to two or more (multiple) instruments. Rather than using a second full featured instrument, the second instrument can include a motor spinner drive assembly or separation sub-assembly only. The drive assembly or separation sub-assembly can be modularly attached to a fully featured primary instrument. In certain examples, a kit and instrument can be modified so that the kit is extended in parallel and a second unused instrument is utilized as a slave device to effectively double the separation speed. In certain examples, the master or primary instrument can be retrofit with an add-on second instrument (e.g., a slave instrument). Certain examples can be extended to other apheresis processes and devices (e.g., in addition to plasmapheresis).

FIG. 7 shows an example three-port plasma separation or filtration device 700. Whole blood goes into the device 700 via a first port 710, where a spinning membrane or other separation means inside a chamber 720 separates plasma from the cellular components. The chamber 720 outputs plasma via a second port 730 and red cell contents via a third port 740.

FIG. 8 shows example modifications to a "standard" separation device. The example new extensible kit is referred to as the "master" device 810 and is configured as a standard device with the exception of sealed-off Tees (A, B, C) at each of three ports 812, 814, 816. A "slave" device 820 of the example includes a

filtration or separation sub-assembly only, which is capable of being connected to the master device 810 at the Tees using lengths of plastic tubing AA', BB', and CC'. The connections are quick-connect screw-on type connections, for example. Using master and slave devices 810, 820, an additional volume of a targeted blood component can be extracted from a single quantity or batch of blood drawn from a donor or other blood source. Rather than processing the batch of blood once through the standard device, the batch of blood can be passed through the master device 810 and then through the slave device 820 to increase an amount of targeted component separated and collected from the blood before it is returned to the donor or other blood source, for example.

While the devices may be referred to as master and slave devices, in certain examples, the devices operate equally in parallel. In certain examples, the master device drives or controls operation in the slave device. Alternatively or in addition, the slave device can only include a portion of the components found in the master separation device sufficient to operate with the master device to filter or separate blood.

FIG. 9 shows the master and slave devices 910, 915 mounted in master and slave instruments 920, 925. One device instrument 920 is designated the master device, and the master device 910 is mounted on that device instrument. The master device instrument 920 runs and controls a blood component collection procedure with a donor or other blood source. The second instrument 925 is designated the slave and is powered on by and in close proximity to the master instrument 920. The slave unit 925 is connected to the master unit 920 via an electronic communication link which allows the master instrument 920 to control the speed of the filter/spinner/separation assembly on the slave device 925 which then runs in a "slave" mode. The extension slave device 915 is mounted on the slave instrument 925, and tube(s) 930 are connected between the master device 910 and slave device 915.

The master-slave configuration 900 effectively allows for parallel separation to occur on both instruments simultaneously (or at least substantially simultaneously). Modifications can be made in the software running an instrument to account for tube lengths between the instruments for priming and device residual purposes. If a speed increase is not desired or necessary, the user can have the option of running just the master device on one single master instrument,

with the Tees on the master device sterile capped off. In certain examples, the master-slave configuration 900 can be extended to include one or more slave units in conjunction with a primary instrument. The device filter or separation sub-assembly can be modularly expanded multiple times, for example.

In certain examples, rather than a full-featured secondary slave instrument, a special spinner drive motor assembly or other separation sub-assembly can be mechanically and electronically attached to the primary instrument to act as the slave device. The motor drive or separation sub-assembly can be a modular unit that can be plugged in and out of the primary device as needed or desired. In certain examples, one, two, or more of the slave motor drive or separation sub-assembly units can be modularly attached to a single primary instrument to increase the processing speed multi-fold in conjunction with a multiply expanded kit. In certain examples, units can be connected by belts or gears based on a fixed speed ratio.

In certain examples, an Autopheresis-C® disposable kit or other suitable blood processing system is modified such that the outlet of the original spinning membrane separation device or separation sub-assembly is connected to a second spinning membrane separation device or separation sub-assembly powered by a separate external spinner assembly or other suitable actuation device.

Certain such example configurations can generate return hematocrits in excess of 80%. Previous tests had shown that a single spinning membrane separation device can generate return hematocrits of 65-70%. The increase in separation efficiency can reduce procedure times (e.g., up to eighteen minutes from Turbo field data) if implemented in the field.

An increase in available membrane surface area from arranging multiple spinning membrane separation devices in series (or the corresponding increase in the separation region of a different multi-separation device arrangement) allows for increased separation efficiency. Alternatively or in addition, surface area or separation region size can be doubled by creating a single spinning membrane separation device or other separation device that is twice the length of the current device and/or by changing other dimension(s) of the spinning membrane separation device or other separation device, for example.

In certain examples, turbulent mixing and/or cell rest period occurring in a length of tubing between linked spinning membrane separation devices or separation sub-assemblies can be beneficial. In certain examples, a separation device can be redesigned to create additional turbulent mixing and/or rest periods to mimic this configuration. In certain examples, plasma collection port configurations can be implemented as separate entities and/or joined together.

In the example of FIG. 10, two spinning membrane separation devices 1010, 1020 are linked in series. While FIG. 10 is illustrated with two spinning membrane separation devices, it should be understood that the principles illustrated in FIG. 10 and described herein may be deployed in combination with other types of plasma separation devices. As shown in the example of FIG. 10, an inlet 1012 receives blood from a donor or other blood source connected by a needle or other access device and line to the device 1010. The separation device 1010 separates at least some plasma from the remainder of the blood and provides plasma to a plasma container via an outlet 1016 and remaining blood through an outlet 1014. A tube 1030 routes the blood from the outlet 1014 to the second separation device 1020. Blood enters the second separation device 1020 through an inlet 1022 and is separated into plasma and remaining component(s) in the device 1020. Additional collected plasma is routed to the plasma collection container via an outlet 1026, and remaining blood component(s) exit the device 1020 via an outlet 1024 to be returned to the donor or other blood source.

When operating in series, a spinning speed of a second spinning membrane separation device (or the processing rate of a different plasma separation device) can be adjusted based on one or more flow rates (e.g., red blood cell and/or plasma) from the first device. Red cells are fragile, and subjecting them to high shear can cause hemolysis. This risk for hemolysis generation increases with increasing blood viscosity (increasing hematocrit). In series, the second of the two separation devices can be spun at slower speed, reducing the risk of generating hemolysis in the higher hematocrit blood, for example.

Two linked spinning membrane separation devices or other plasma separation devices provide higher exit hematocrit than a single spinning membrane separation device or other plasma separation device, even when the rest of the disposable kit is identical (or substantially identical) to a single

separation configuration. Hematocrit increases can be facilitated by increased surface area, cell rest period in a linking line (e.g., tube), mixing in the linking line, a combination of these factors, etc.

FIG. 11 depicts an example flow diagram representative of process(es) that may be used with respect to examples described herein. The example process(es) of FIG. 11 may be driven using a processor, a controller and/or any other suitable processing device. Although the example process(es) of FIG. 11 are described with reference to the flow diagram of FIG. 11, other methods of implementing the process(es) of FIG. 11 may be employed. For example, the order of execution of the blocks may be changed, and/or some of the blocks described may be changed, eliminated, sub-divided, or combined. Additionally, any or all of the example process(es) of FIG. 11 may be performed sequentially and/or in parallel and with any blood component being targeted for separation and collection.

FIG. 11 depicts a flow diagram for an example method 1100 for plasma collection from a donor. While FIG. 11 illustrates an exemplary method of collecting plasma from a donor using a plurality of filtration devices, it should be understood that the method is not limited to the processing of blood from a donor using a plurality of filtration devices, but may include the processing of blood from any blood source and using a plurality of any other suitable plasma separation devices. At block 1105, blood is drawn into a plasma and/or other blood component collection system from a donor or other blood source using a pump to pull blood along a blood source draw line. The blood source draw line is placed in the open position with a first binary clamp to allow blood flow while a return processing line is closed using a second binary clamp to prevent blood flow through the return line. At block 1110, the WB is pumped into a first spinning membrane filtration device or other plasma separation device through a port of the filtration or separation device. At block 1115, within the first filtration or separation device, the WB is separated by spinning and passing through one or more membrane filters or other plasma separation means. At block 1120, plasma is collected in a plasma collection container or reservoir.

At block 1125, remaining blood component(s) are routed to a second spinning membrane filtration device or other plasma separation device through an output port in the first filtration or separation device. At block 1130, within the

second filtration or separation device, the remaining blood component(s) are separated by spinning and passing through one or more membrane filters or other plasma separation means. At block 1135, plasma is collected in a plasma collection container or reservoir. The plasma collection container/reservoir can be the same and/or a different container from that connected to the first filtration or separation device, for example. At block 1140, remaining blood component(s) are routed from the second filtration or separation device via an output port for return to the donor or other blood source.

In the example of FIG. 12, membrane limited transport 1210 is compared with red cell layer limited transport 1220. A plasma flow rate, Q_P, is plotted against a transmembrane pressure, ΔP_{TM}, for both membrane limited transport 1215 and red cell layer limited transport 1225. As shown in the example of FIG. 12, for membrane-limited transport, plasma flow rate increases with both increasing pressure and membrane permeability, P, whereas, with red-cell-layer limited transport, plasma flow rate is invariant with transmembrane pressure and increases with a mass transfer coefficient, k. For membrane limited transport, plasma flow rate can be calculated as follows:

$$Q_P = A_E P \Delta P_{TM}, \qquad (16)$$

where A_E represents an effective membrane area.

For red cell layer limited transport, plasma flow rate (Q_P) can be calculated as follows:

$$Q_P = A_E k \ln(H_W / H_B), \qquad (17)$$

where H_W represents a wall hematocrit (or local hematocrit of the concentrated red cell solution adjacent to the membrane wall) and H_B represents a local bulk fluid hematocrit away from the wall. H_W is a function of the system/fluid. While the H_W may not be truly known, it can be estimated to be near 90%, meaning that the remaining 10% plasma is not able to be forced from the system.

As shown in the example of FIG. 13, a combined transport behavior can be evaluated using both membrane limited transport and red cell layer limited transport. Additionally, FIG. 14 illustrates an example graph of transmembrane pressure (TMP) versus plasma flow rate, where a collection device operates in a plasma demand mode with the pressure as a dependent variable. As a result, a

concentration polarization model 1500 can be formed for red cell layer limited transport, as illustrated in the example of FIG. 15. Using the model 1500, a plasma flow rate 1510 can be determined as follows:

$$\frac{dQ_P}{dz} = \phi C k(z) \ln\left[\frac{H_W}{H_I}\left(1-\frac{Q_P}{Q_I}\right)\right] \qquad (18)$$

where ϕ is the fraction of membrane available for transport and C is the membrane circumference.

In the equation above, k varies from inlet to outlet, and the cumulative plasma flow rate is obtained by integrating along a length, z, of the device. As shown in FIG. 15, a determination 1520 of a mass transfer coefficient, k, for a device length, z, is determined using a rotation speed, ω; a rotor radius, R_R; a gap, $G(z)$; and a blood viscosity, $v[H(z)]$:

$$k(z) = M\left[\frac{R_R^{0.913}\omega^{3/2}}{G(z)^{0.247}v^{1/2}}\right]. \qquad (19)$$

Thus, certain examples provide increased effective membrane area to increase device performance. Similar performance benefits may be achieved in combination with other types of blood component separation devices and are not limited to only membrane-type separators. Increased effective membrane area can be provided via collection of plasma both on draw and on return and/or by coupling multiple membrane filtration devices together in parallel and/or in series for blood filtration to remove and capture plasma before returning remaining blood components to a donor. Certain examples allow plasma filtering to continue without affect from transition times between cycles.

Although the forgoing discloses example methods, apparatus, systems, and articles of manufacture including, among other components, firmware and/or software executed on hardware, it should be noted that such methods, apparatus, systems and articles of manufacture are merely illustrative and should not be considered as limiting. For example, it is contemplated that any or all of these firmware, hardware, and/or software components could be embodied exclusively in hardware, exclusively in software, exclusively in firmware, or in any combination of hardware, software, and/or firmware. Accordingly, while the following describes example methods, apparatus, systems, and/or articles of manufacture, the

examples provided are not the only way(s) to implement such methods, apparatus, systems, and/or articles of manufacture.

Certain examples can include processes that can be implemented using, for example, computer readable instructions that can be used to facilitate mobile blood applications for donors, operators, administrators, and/or providers. The example processes can be performed using a processor, a controller and/or any other suitable processing device. For example, the example processes can be implemented using coded instructions (e.g., computer readable instructions) stored on a tangible computer readable medium such as a flash memory, a read-only memory (ROM), and/or a random-access memory (RAM). As used herein, the term tangible computer readable medium is expressly defined to include any type of computer readable storage and to exclude propagating signals. Additionally or alternatively, the example processes can be implemented using coded instructions (e.g., computer readable instructions) stored on a non-transitory computer readable medium such as a flash memory, a read-only memory (ROM), a random-access memory (RAM), a CD, a DVD, a Blu-ray, a cache, or any other storage media in which information is stored for any duration (e.g., for extended time periods, permanently, brief instances, for temporarily buffering, and/or for caching of the information). As used herein, the term non-transitory computer readable medium is expressly defined to include any type of computer readable medium and to exclude propagating signals.

Alternatively, some or all of the example processes can be implemented using any combination(s) of application specific integrated circuit(s) (ASIC(s)), programmable logic device(s) (PLD(s)), field programmable logic device(s) (FPLD(s)), discrete logic, hardware, firmware, etc. Also, some or all of the example processes can be implemented manually or as any combination(s) of any of the foregoing techniques, for example, any combination of firmware, software, discrete logic and/or hardware. Further, although example processes may be described with reference to a particular order and/or structure, other methods of implementing the processes may be employed. For example, the order of execution of the blocks can be changed, and/or some of the blocks described may be changed, eliminated, sub-divided, or combined. Additionally, any or all of the example processes can be performed sequentially and/or in parallel by, for

example, separate processing threads, processors, devices, discrete logic, circuits, etc.

Aspects of the present subject matter described above may be beneficial alone or in combination with one or more other aspects. Without limiting the foregoing description, in accordance with one aspect of the subject matter herein, there is provided a method for processing blood. The method includes separating blood into targeted and non-targeted components using a separation device and flowing out of the separation device, during a first time period, at least a portion of the targeted component separated from the non-targeted component via the separation device. The non-targeted component is re-processing to remove additional targeted component using the separation device.

In accordance with another aspect which may be used or combined with the preceding aspect, at least a portion of the targeted component flowed out of the separation device is collected.

In accordance with another aspect which may be used or combined with any of the preceding aspects at least a portion of the additional targeted component separated from the non-targeted component is collected.

In accordance with another aspect which may be used or combined with any of the preceding aspects, the blood is separated into targeted and non-targeted components using a separation device including a blood source draw line and a return processing line. The blood source draw line is opened to allow blood flow through the blood source draw line while the return processing line is closed to prevent blood flow through the return processing line during the first time period. The return processing line is opened to allow blood flow through the return processing line while the blood source draw line is closed to prevent blood flow through the blood source draw line during a second time period.

In accordance with another aspect which may be used or combined with any of the preceding aspects, the targeted component is collected during first and second time periods alternating until a target volume is collected.

In accordance with another aspect which may be used or combined with the preceding aspect, the target volume collection is completed during the second time period.

In accordance with another aspect which may be used or combined with any of the preceding aspects, the blood is separated into targeted and non-targeted components using a membrane filter.

In accordance with another aspect which may be used or combined with any of the preceding aspects, the blood is separated into targeted and non-targeted cellular components using a spinning membrane filter.

In accordance with another aspect, there is provided a blood processing system. The system includes first and second separation devices. The first separation device is adapted to receive blood from a blood source and separate a portion of a targeted component from the blood. The second separation device is adapted to receive the non-targeted component remaining after separation by the first separation device and to separate additional targeted component from the non-targeted component.

In accordance with another aspect which may be used or combined with the preceding aspect, the first separation device is adapted to be a master separation device and the second separation device is adapted to be a slave separation device.

In accordance with another aspect which may be used or combined with the preceding aspect, the slave separation device comprises a partial separation device including a separation sub-assembly.

In accordance with another aspect which may be used or combined with the preceding aspect, the separation sub-assembly of the slave separation device comprises a motor spinner drive assembly modularly attached to the master separation device.

In accordance with another aspect which may be used or combined with the preceding three aspects, the master separation device is to be retrofit to add on the slave separation device.

In accordance with another aspect which may be used or combined with the preceding five aspects, the first and second separation devices reside in separate blood processing instruments and are connected to allow blood flow between the instruments.

In accordance with another aspect which may be used or combined with the preceding six aspects, the first and second separation devices are to operate in parallel.

In accordance with another aspect which may be used or combined with the preceding seven aspects, at least one of the first separation device and the second separation device is adapted to recirculate blood remaining after separation to extract additional targeted component from the non-targeted components remaining before the non-targeted component is routed back to the blood source.

In accordance with another aspect, there is provided a method for processing blood. The method includes separating blood into targeted and non-targeted components using a first separation device. At least a portion of the targeted component and a least a portion of the non-targeted component are flowed out of the first separation device and the non-targeted component is re-processed to remove additional targeted component using a second separation device.

In accordance with another aspect which may be used or combined with the preceding aspect, at least a portion of the targeted component separated from the non-targeted component is collected.

In accordance with another aspect which may be used or combined with the preceding two aspects, at least a portion of the additional targeted component separated from the non-targeted component via the second separation device is collected.

In accordance with another aspect which may be used or combined with the preceding three aspects, the first separation device comprises a master separation device and the second separation device comprises a slave separation device.

In accordance with another aspect which may be used or combined with the preceding four aspects, the first separation device and the second separation device are to operate in parallel.

In accordance with another aspect which may be used or combined with the aforementioned seventeenth through twentieth aspects, the targeted component is separated from blood during a first time period and separated from the remaining non-targeted component during a second time period.

In accordance with another aspect which may be used or combined with any of the preceding aspects, the targeted component is plasma and the non-targeted component is cellular blood components.

It will be understood that the embodiments described above are illustrative of some of the applications of the principles of the present subject matter. Numerous modifications may be made by those skilled in the art without departing from the spirit and scope of the claimed subject matter, including those combinations of features that are individually disclosed or claimed herein. For these reasons, the scope hereof is not limited to the above description but is as set forth in the following claims.

CLAIMS

1. A blood processing method comprising:

separating blood into a targeted component and a non-targeted component using a separation device;

flowing out of the separation device, during a first time period, at least a portion of the targeted component separated from the non-targeted component via the separation device; and

re-processing the non-targeted component to remove additional targeted component using the separation device.

2. The method of claim 1, wherein said flowing out of the separation device includes collecting at least a portion of the targeted component separated from the non-targeted component.

3. The method of any of the preceding claims, further comprising collecting, during a second time period, at least a portion of the additional targeted component separated from the non-targeted component via the separation device.

4. The method of any of the preceding claims, wherein said separating blood includes

separating blood into targeted and non-targeted components using a separation device comprising a blood source draw line and a return processing line;

opening the blood source draw line to allow blood flow through the blood source draw line while closing the return processing line to prevent blood flow through the return processing line during the first time period; and

opening the return processing line to allow blood flow through the return processing line while closing the blood source draw line to prevent blood flow through the blood source draw line during a second time period.

5. The method of any of the preceding claims, wherein the targeted component is collected during first and second time periods alternating until a target volume is collected.

6. The method of claim 5, wherein target volume collection is completed during the second time period.

7. The method of any of the preceding claims, wherein said separating blood includes separating blood into targeted and non-targeted components using a separation device comprising a membrane filter.

8. The method of any of the preceding claims, wherein said separating blood includes separating blood into targeted and non-targeted components using a separation device comprising a membrane filter.

9. The method of any of the preceding claims, wherein the targeted component comprises plasma and the non-targeted component comprises cellular blood components.

10. A blood processing system comprising:

a first separation device; and

a second separation device, wherein the first separation device is adapted to receive blood from a blood source and separate a portion of a targeted component from the blood and the second separation device is adapted to receive a non-targeted component remaining after separation by the first separation device and to separate additional targeted component from the non-targeted component.

11. The system of claim 10, wherein the first separation device is adapted to be a master separation device and the second separation device is adapted to be a slave separation device.

12. The system of claim 11, wherein the slave separation device comprises a partial separation device including a separation sub-assembly.

13. The system of claim 12, wherein the separation sub-assembly of the slave separation device comprises a motor spinner drive assembly modularly attached to the master separation device.

14. The system of any of claims 11-13, wherein the master separation device is to be retrofit to add on the slave separation device.

15. The system of any of claims 10-14, wherein the first and second separation devices reside in separate blood processing instruments and are connected to allow blood flow between the instruments.

16. The system of any of claims 10-15, wherein the first and second separation devices are to operate in parallel.

17. The system of any of claims 10-16, wherein at least one of the first separation device and the second separation device is adapted to recirculate blood remaining after separation to extract additional targeted component from the non-targeted component remaining before the non-targeted component is routed back to the blood source.

18. The system of any of claims 10-17, wherein the targeted component comprises plasma and the non-targeted component comprises cellular blood components.

19. A blood processing method comprising:

separating blood into a targeted component and a non-targeted component using a first separation device;

flowing out of the first separation device at least a portion of the non-targeted component and at least a portion of the targeted component separated from the non-targeted component via the first separation device; and

re-processing the non-targeted component to remove additional targeted component using a second separation device.

20. The method of claim 19, wherein said flowing out of the separation device includes collecting at least a portion of the targeted component separated from the non-targeted component.

21. The method of any of claims 19-20, further comprising collecting at least a portion of the additional targeted component separated from the non-targeted component via the second separation device.

22. The method of any of claims 19-21, wherein the first separation device comprises a master separation device and the second separation device comprises a slave separation device.

23. The method of any of claims 19-22, wherein the first separation device and the second separation device are to operate in parallel.

24. The method of any of claims 19-22, wherein said separating occurs during a first time period and said re-processing occurs during a second time period.

25. The method of any of claims 19-24, wherein the targeted component comprises plasma and the non-targeted component comprises cellular blood components.

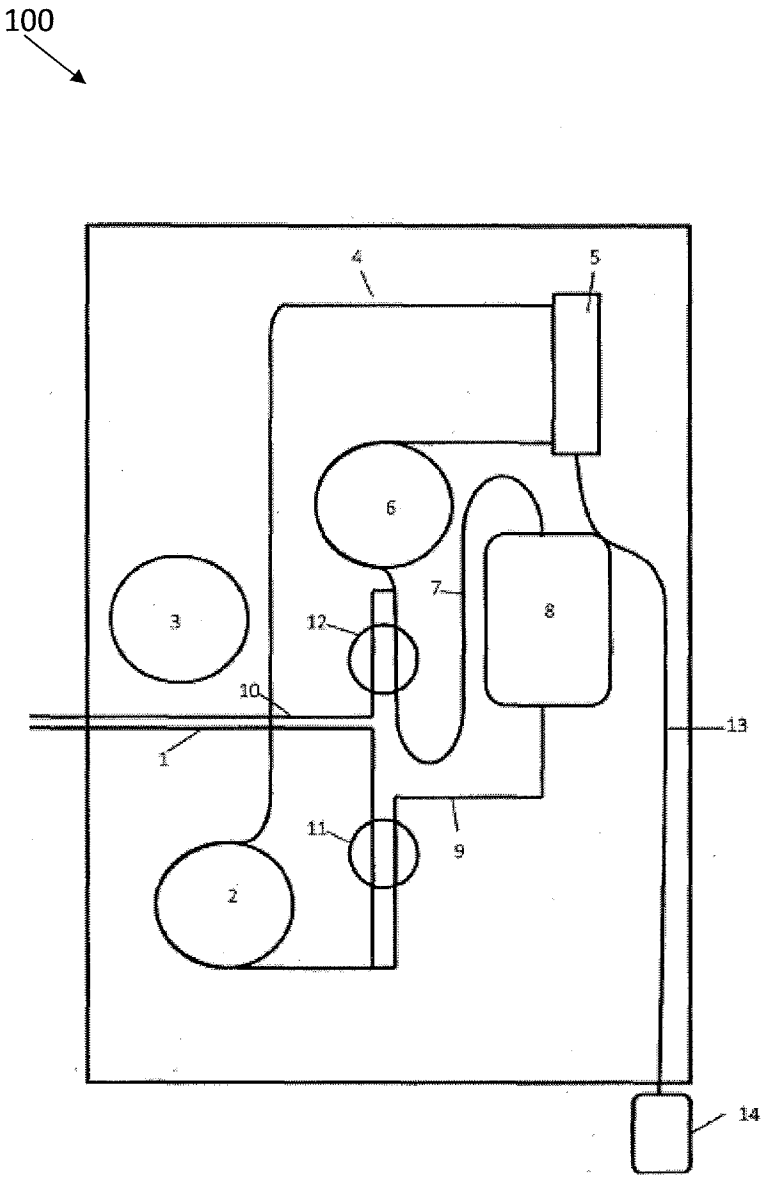


FIG. 1

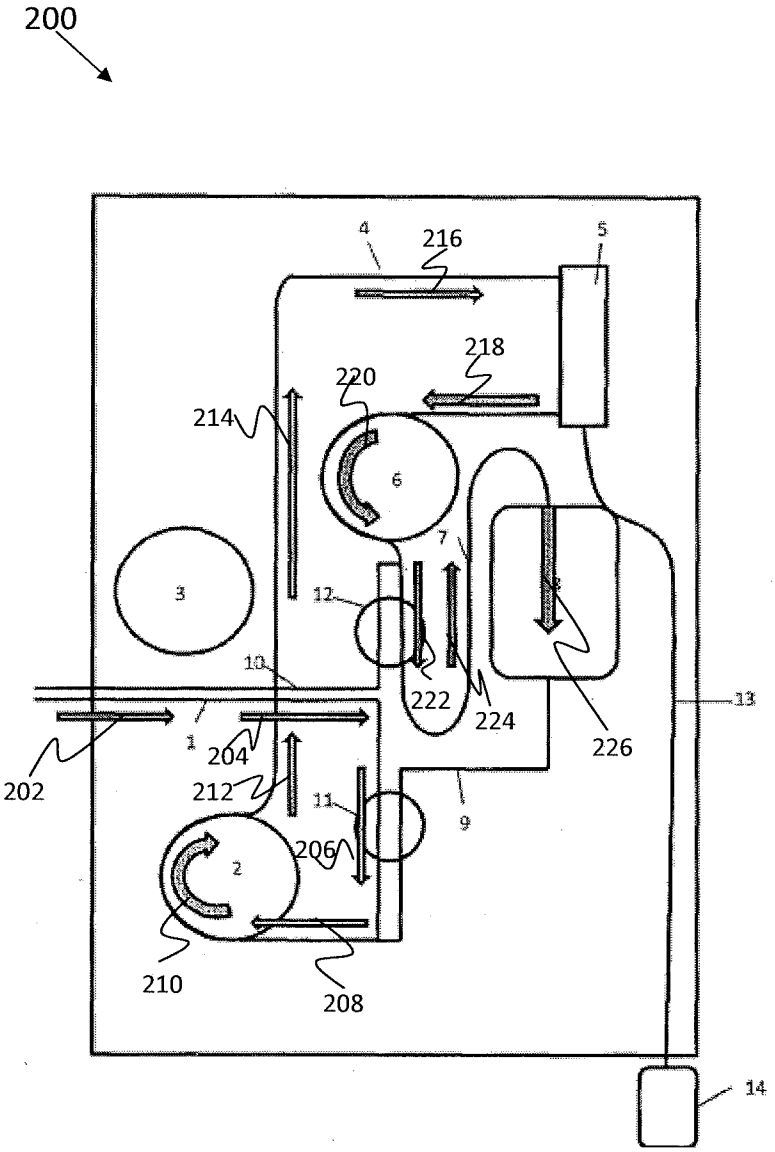

200
4
216
5
218
220
214
6
7
3
12
8
10
222
224
226
13
1
204
202
212
11
9
206
2
210
208
14

FIG. 2

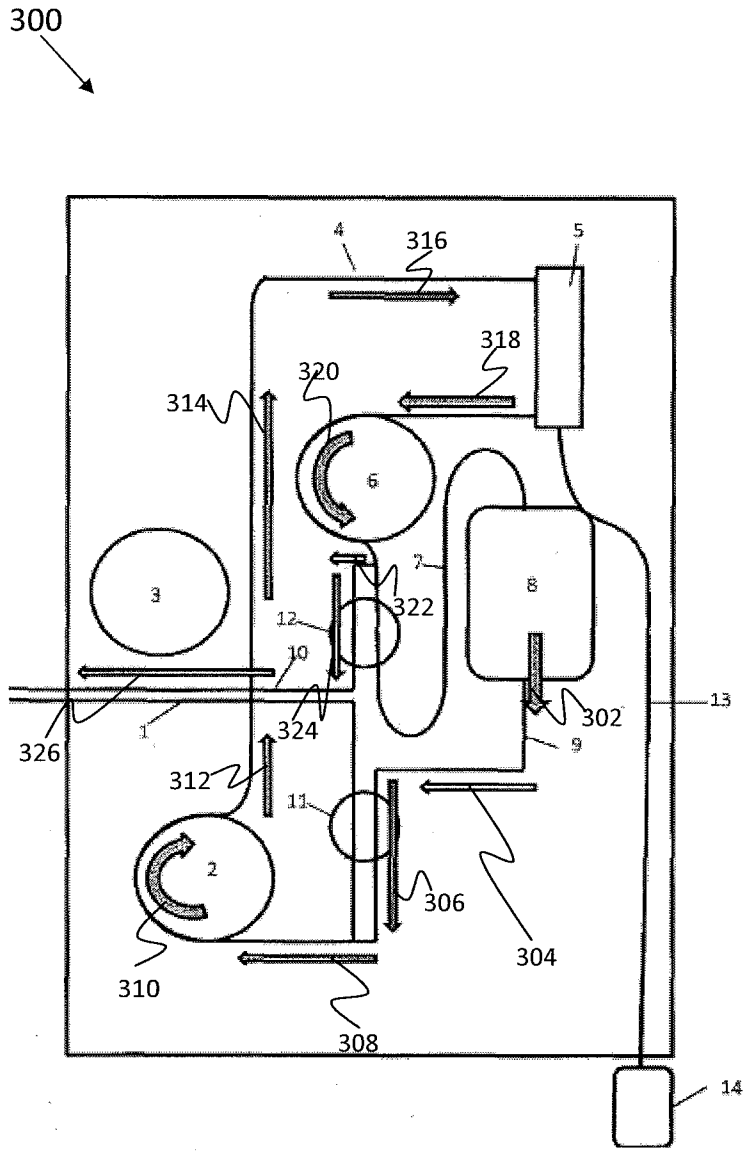

300
4
316
5
318
320
314
6
7
8
3
322
12
10
13
302
326
1
324
9
312
11
2
306
304
310
308
14

FIG. 3

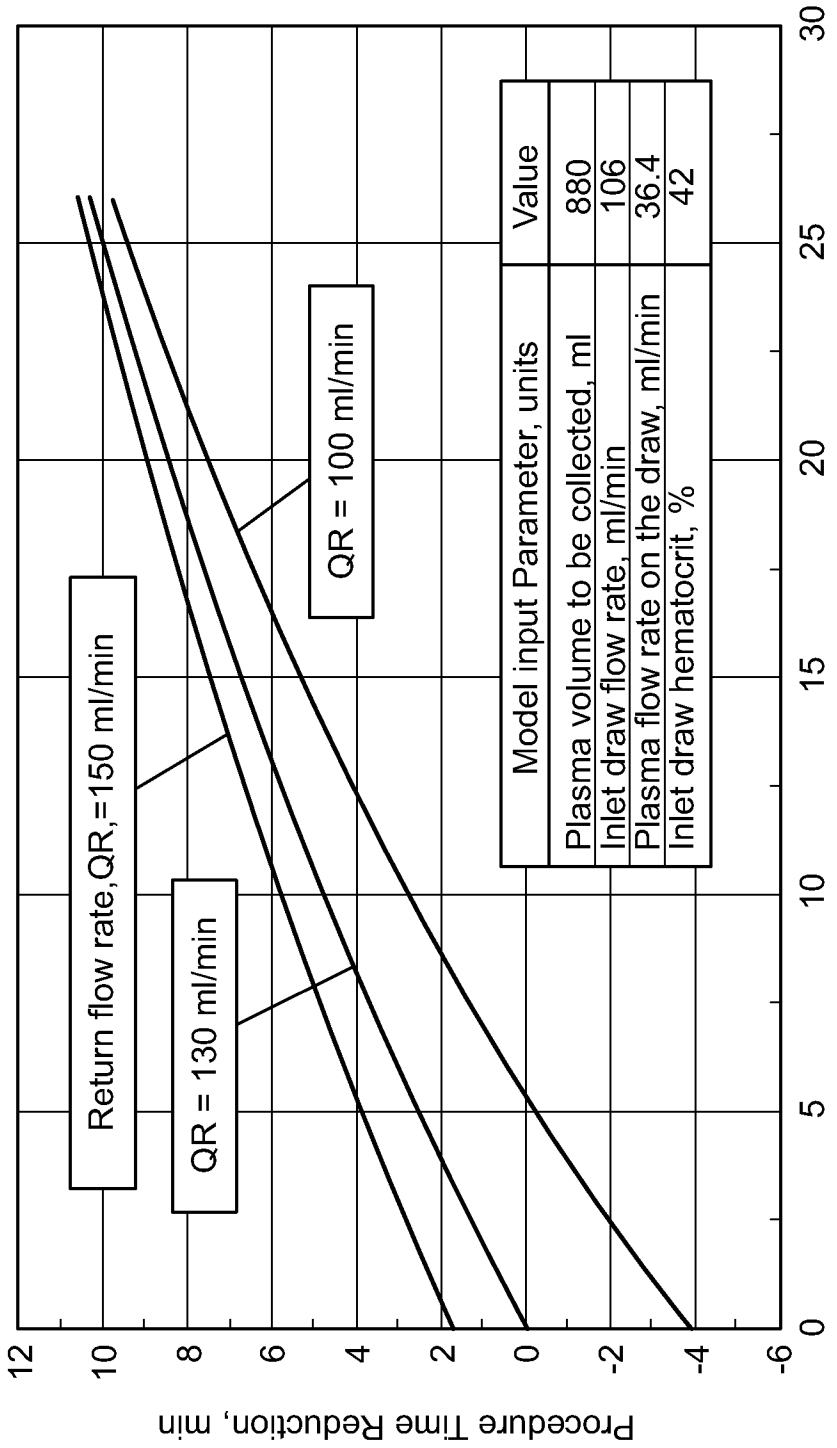

Procedure Time Reduction, min
12
10
8
6
4
2
0
-2
-4
-6
0
5
10
15
20
25
30
Plasma Flow Rate during Return, ml/min
Return flow rate,QR,=150 ml/min
QR = 130 ml/min
QR = 100 ml/min
Model input Parameter, units
Value
Plasma volume to be collected, ml
880
Inlet draw flow rate, ml/min
106
Plasma flow rate on the draw, ml/min
36.4
Inlet draw hematocrit, %
42

FIG. 4

5/13

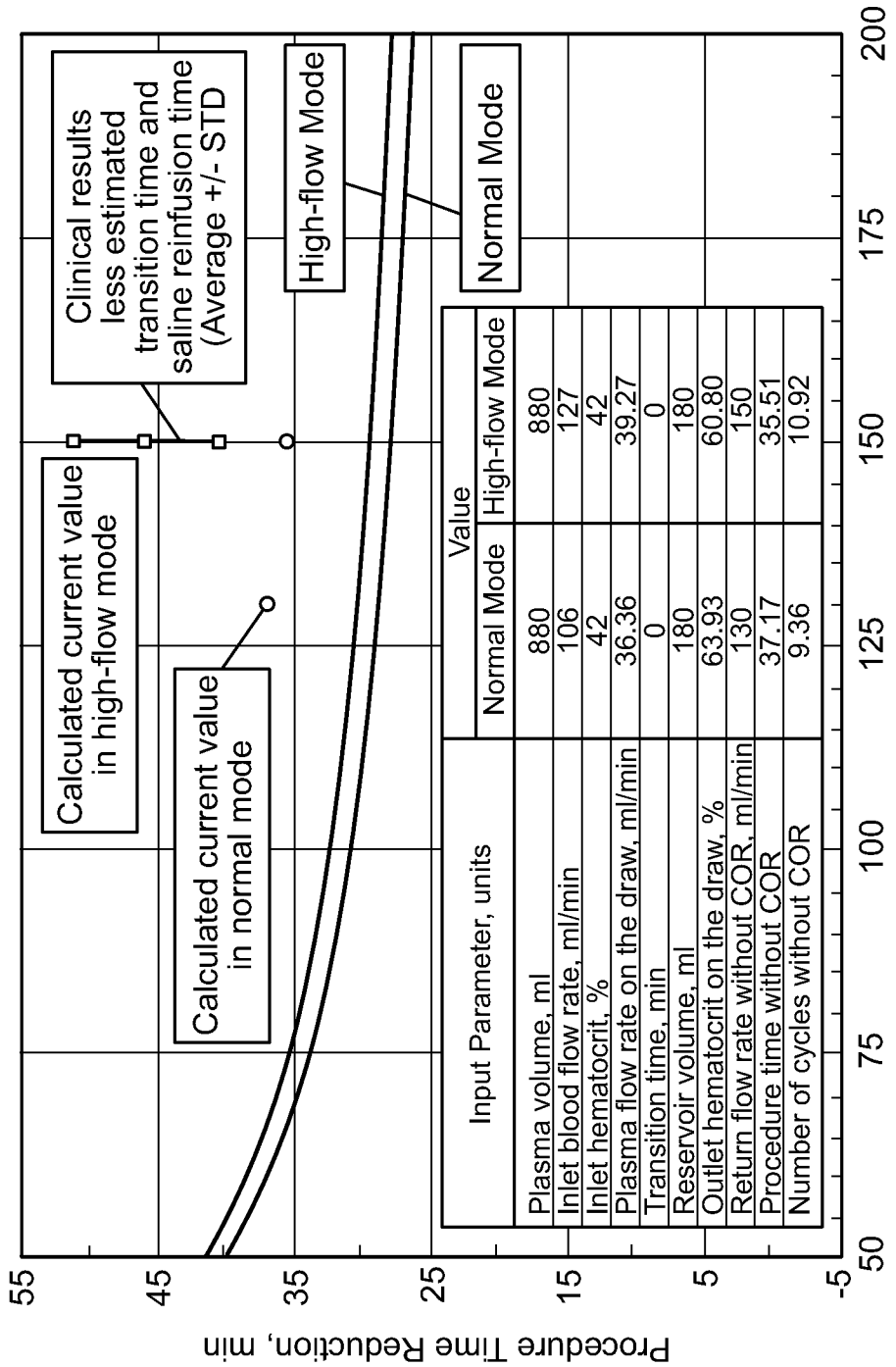

Procedure Time Reduction, min
55
45
35
25
15
5
-5
50
75
100
125
150
175
200
Plasma Flow Rate during Return, ml/min
Calculated current value in high-flow mode
Calculated current value in normal mode
Clinical results less estimated transition time and saline reinfusion time (Average +/- STD
High-flow Mode
Normal Mode
Input Parameter, units
Value
Normal Mode
High-flow Mode
Plasma volume, ml 880 880
Inlet blood flow rate, ml/min 106 127
Inlet hematocrit, % 42 42
Plasma flow rate on the draw, ml/min 36.36 39.27
Transition time, min 0 0
Reservoir volume, ml 180 180
Outlet hematocrit on the draw, % 63.93 60.80
Return flow rate without COR, ml/min 130 150
Procedure time without COR 37.17 35.51
Number of cycles without COR 9.36 10.92

FIG. 5

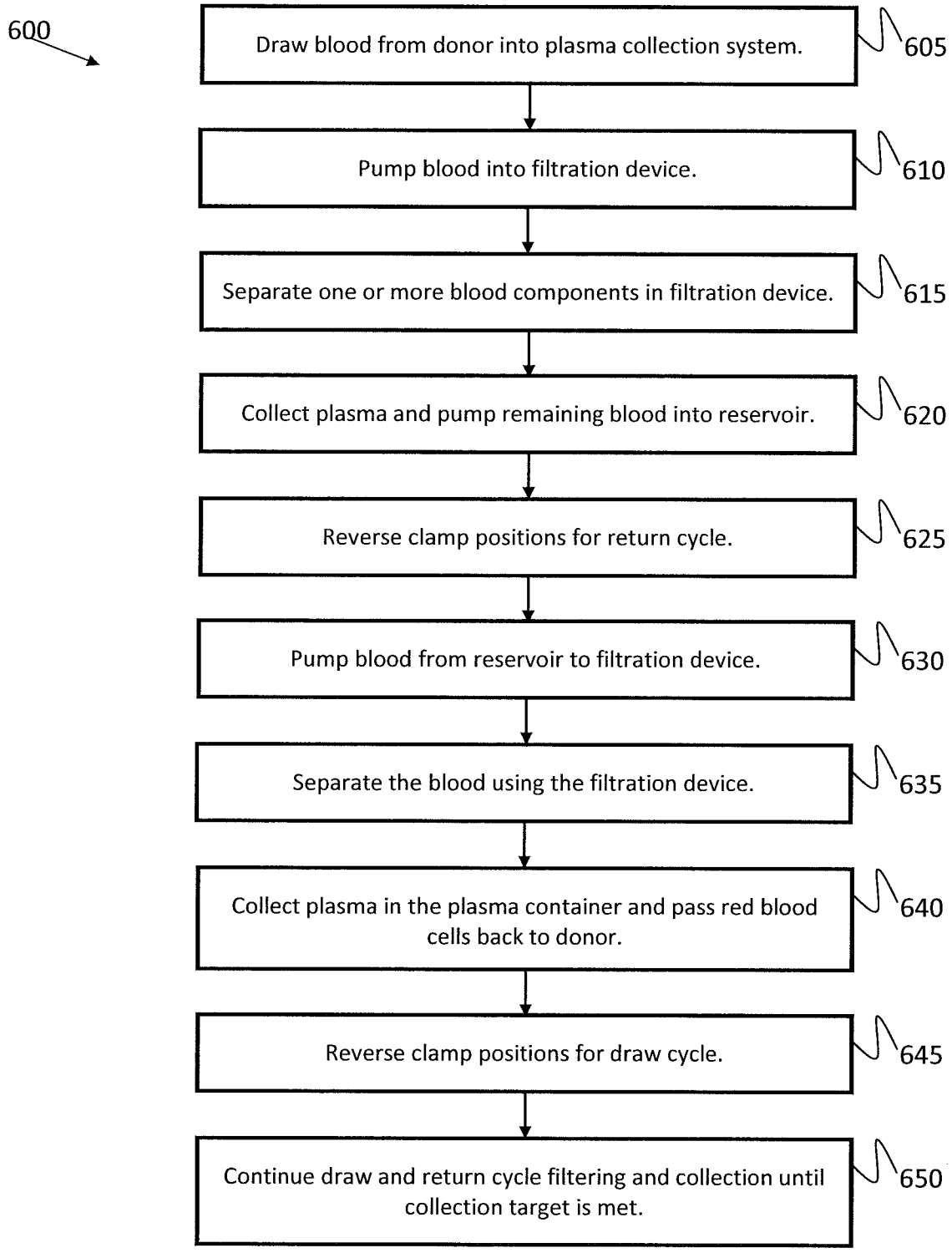

600
Draw blood from donor into plasma collection system.
605
Pump blood into filtration device.
610
Separate one or more blood components in filtration device.
615
Collect plasma and pump remaining blood into reservoir.
620
Reverse clamp positions for return cycle.
625
Pump blood from reservoir to filtration device.
630
Separate the blood using the filtration device.
635
Collect plasma in the plasma container and pass red blood cells back to donor.
640
Reverse clamp positions for draw cycle.
645
Continue draw and return cycle filtering and collection until collection target is met.
650

FIG. 6

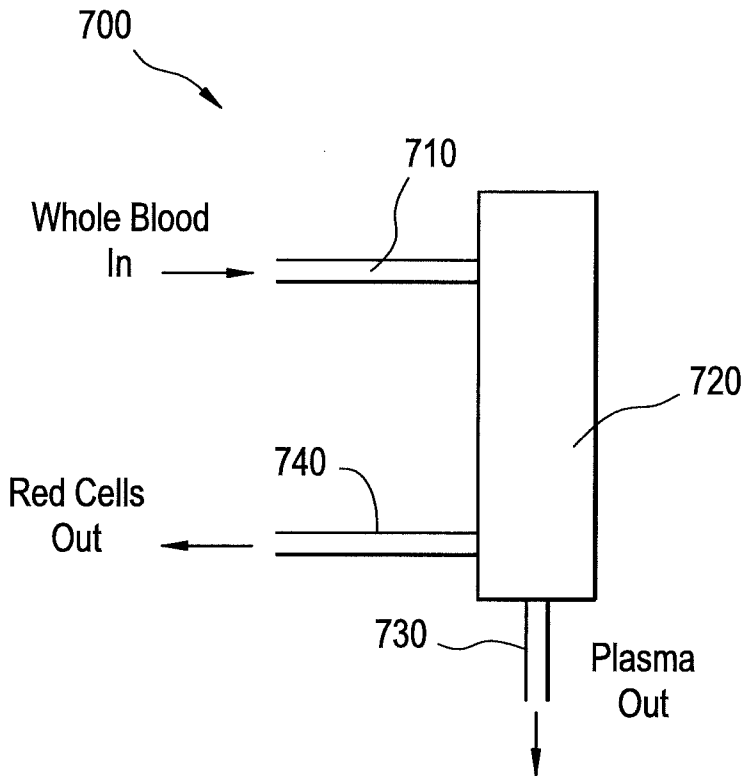


FIG. 7

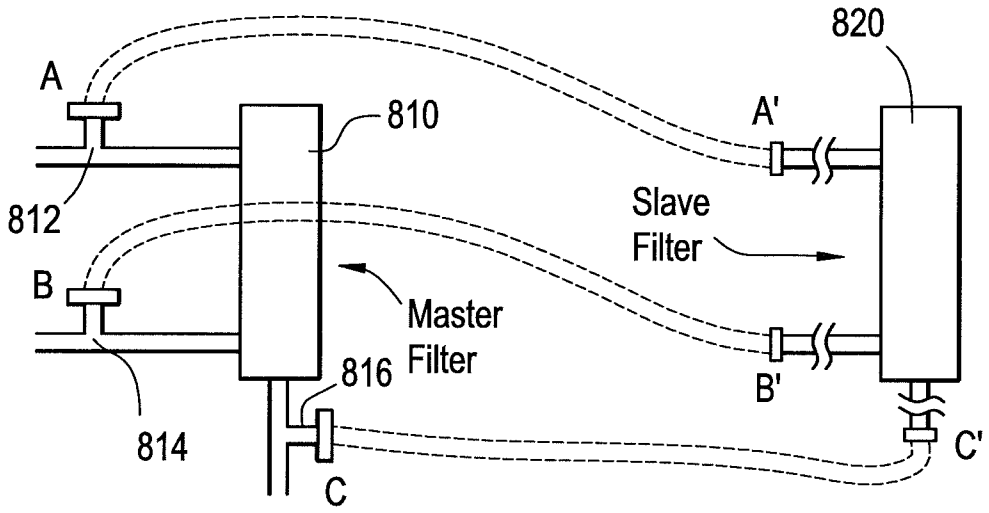

820
A
810
A'
812
Slave
Filter
B
Master
Filter
816
B'
814
C'
C

FIG. 8

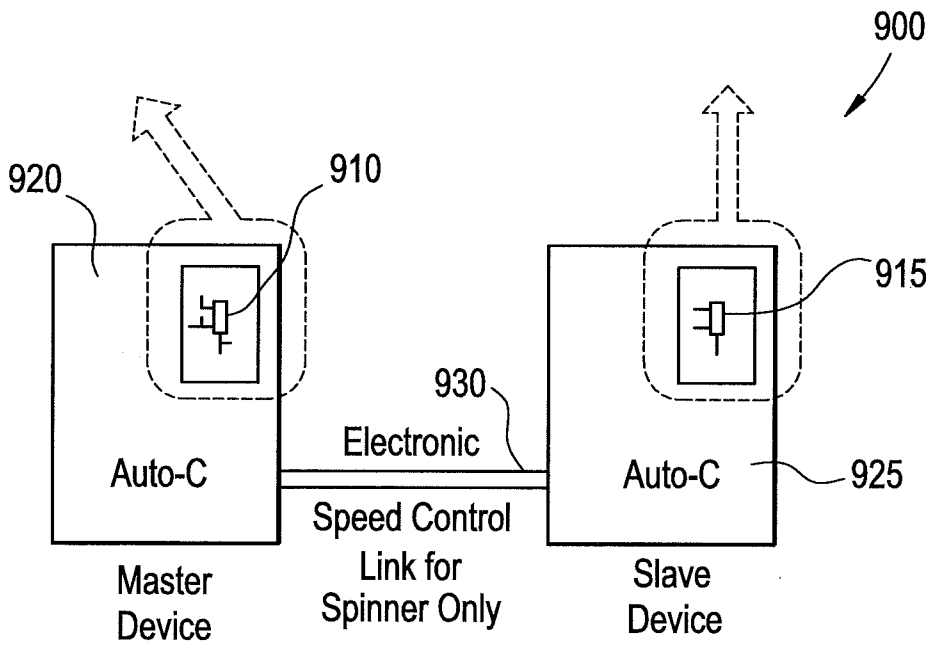

900
920
910
915
930
Electronic
Auto-C
Auto-C
925
Speed Control
Link for
Spinner Only
Master
Device
Slave
Device

FIG. 9

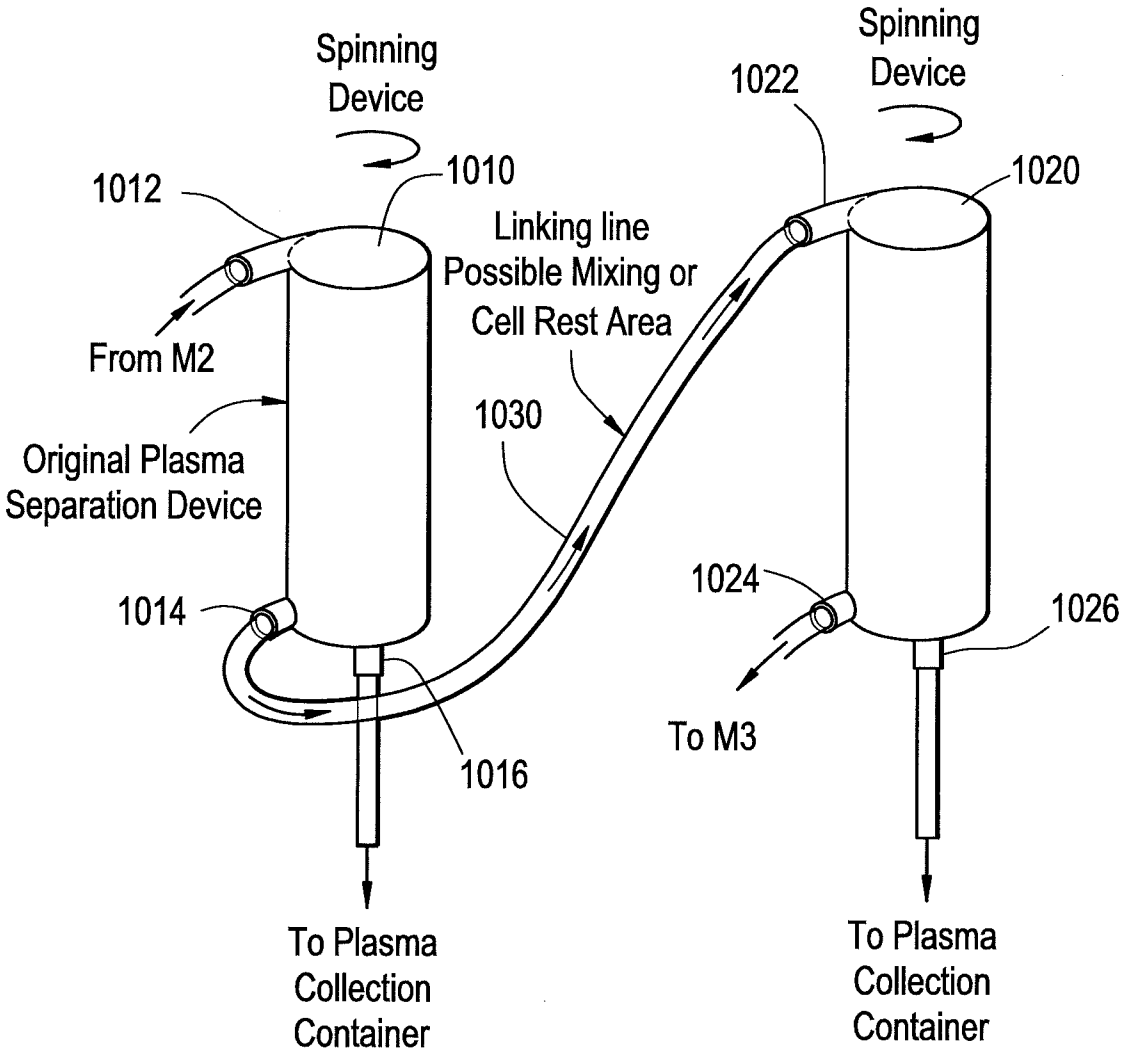

Spinning Device
1010
1012
From M2
Original Plasma Separation Device
1014
1016
To Plasma Collection Container
Linking line Possible Mixing or Cell Rest Area
1030
1022
Spinning Device
1020
1024
1026
To M3
To Plasma Collection Container

FIG. 10

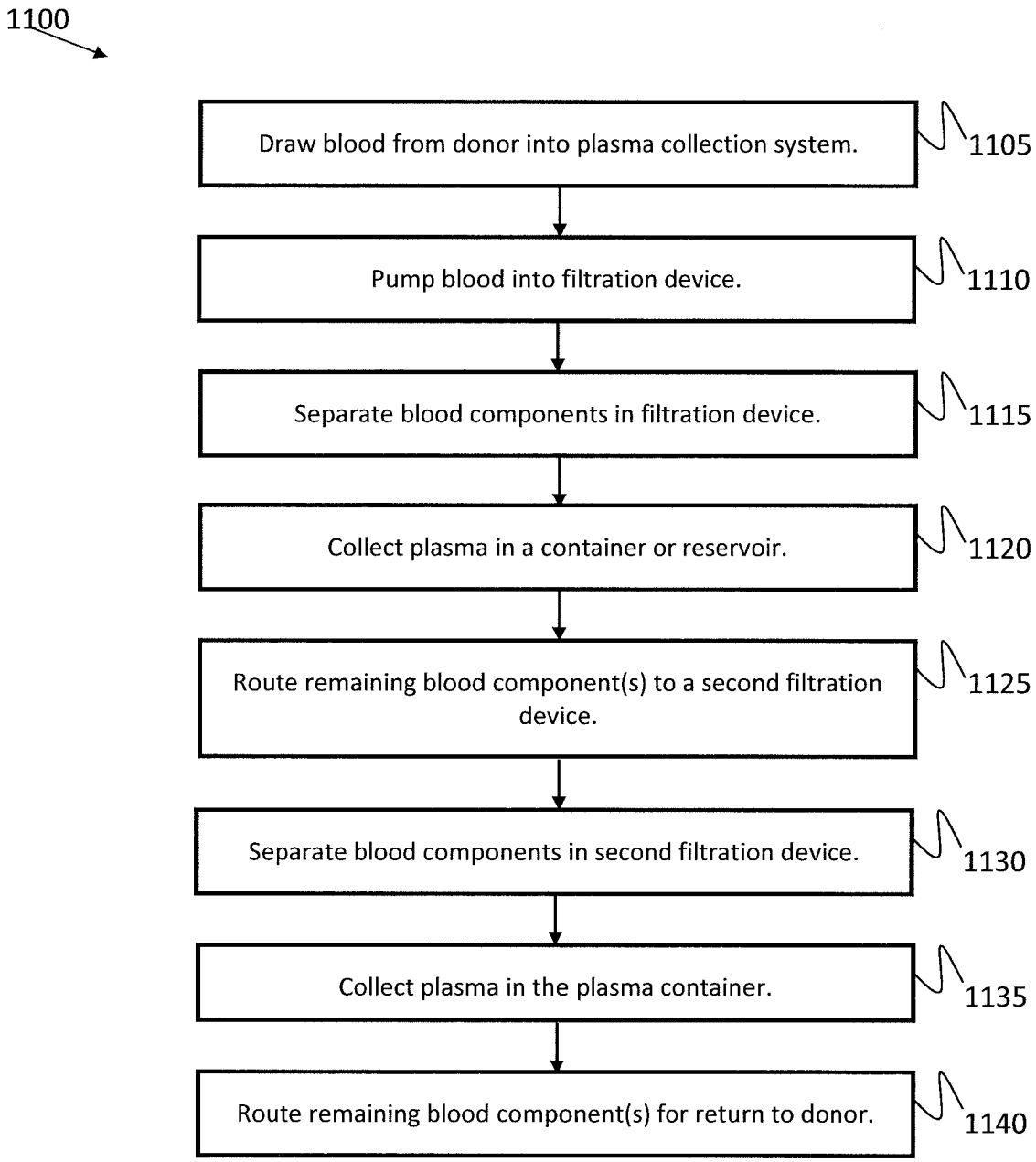

1100
Draw blood from donor into plasma collection system.
1105
Pump blood into filtration device.
1110
Separate blood components in filtration device.
1115
Collect plasma in a container or reservoir.
1120
Route remaining blood component(s) to a second filtration device.
1125
Separate blood components in second filtration device.
1130
Collect plasma in the plasma container.
1135
Route remaining blood component(s) for return to donor.
1140

FIG. 11

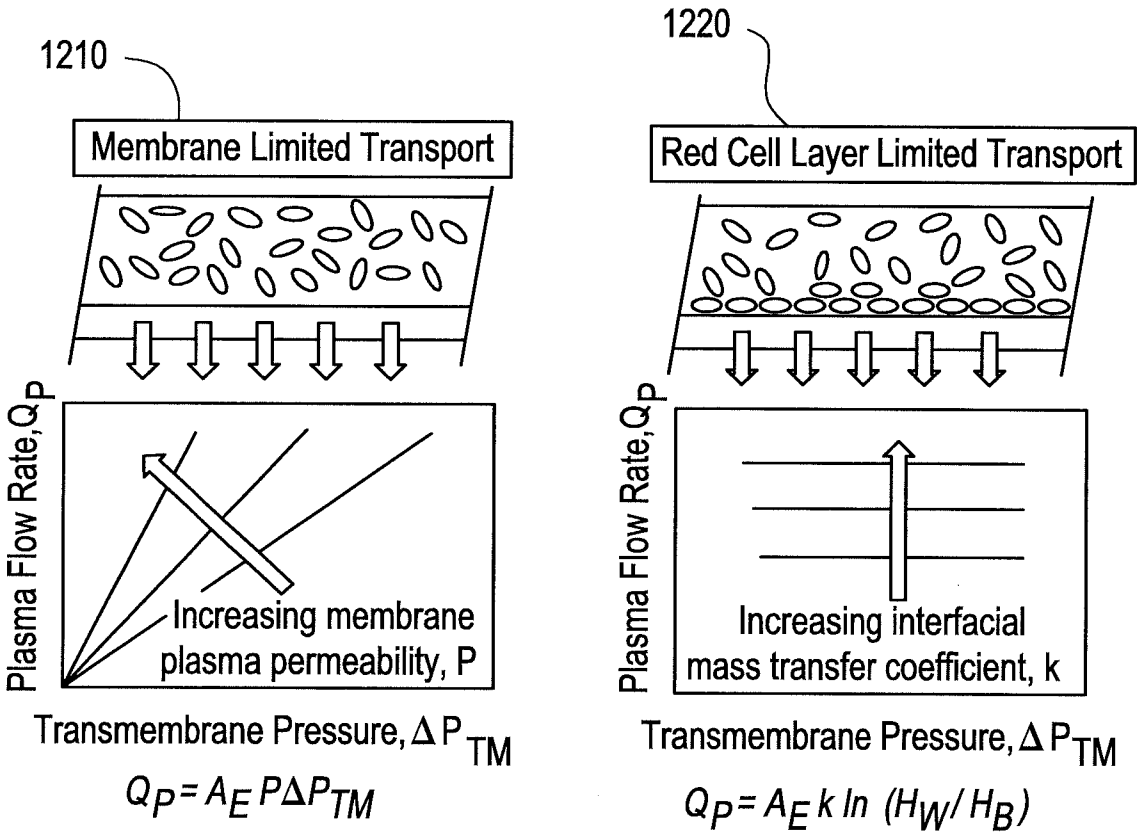

1210
Membrane Limited Transport
Plasma Flow Rate, Q_P
Increasing membrane plasma permeability, P
Transmembrane Pressure, ΔP_{TM}
$Q_P = A_E P \Delta P_{TM}$
1220
Red Cell Layer Limited Transport
Plasma Flow Rate, Q_P
Increasing interfacial mass transfer coefficient, k
Transmembrane Pressure, ΔP_{TM}
$Q_P = A_E k \ln (H_W / H_B)$

FIG. 12

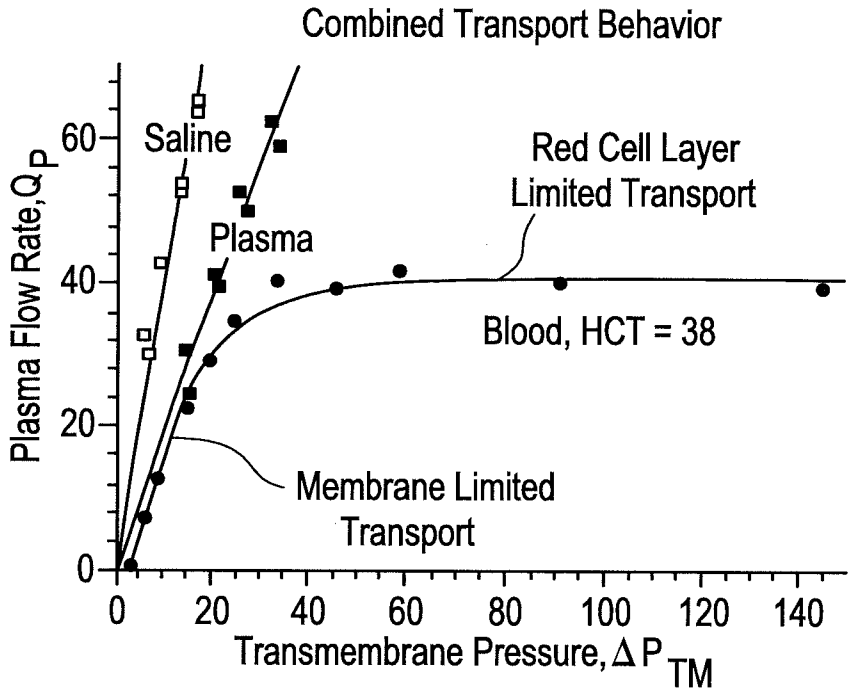

Combined Transport Behavior
Plasma Flow Rate, Q_P
60
40
20
0
Saline
Plasma
Red Cell Layer Limited Transport
Blood, HCT = 38
Membrane Limited Transport
0
20
40
60
80
100
120
140
Transmembrane Pressure, ΔP_{TM}

FIG. 13

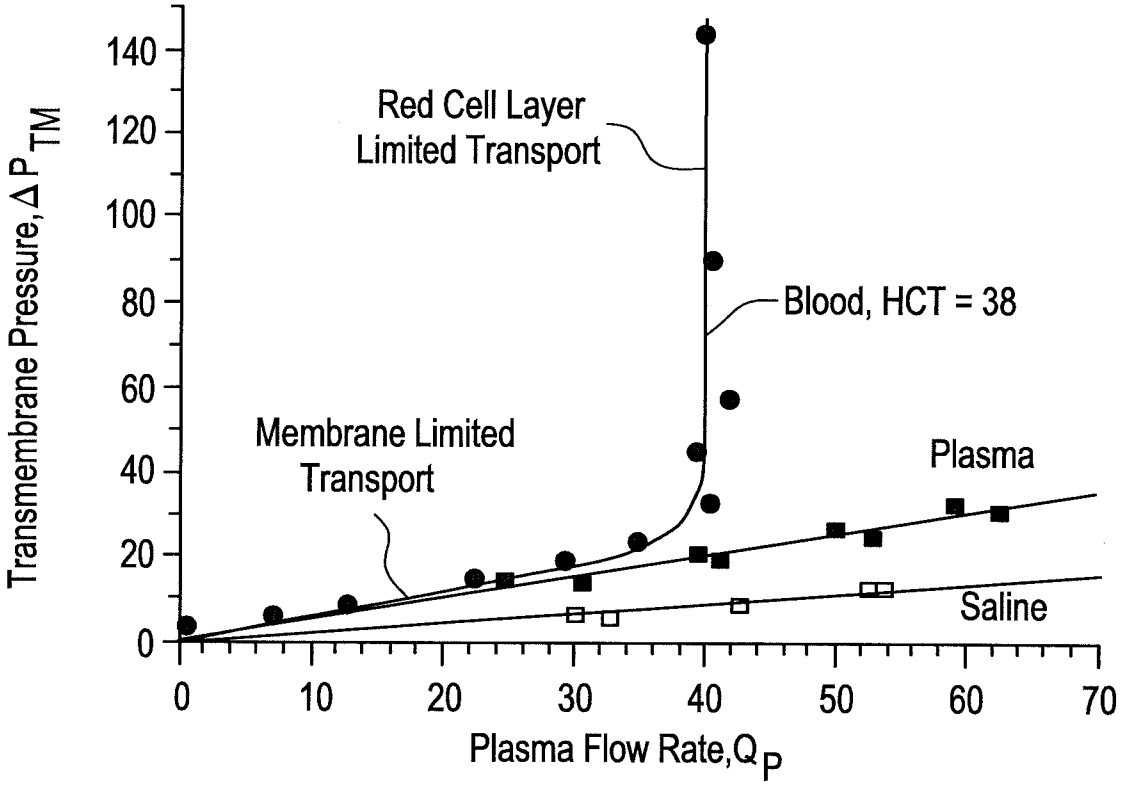
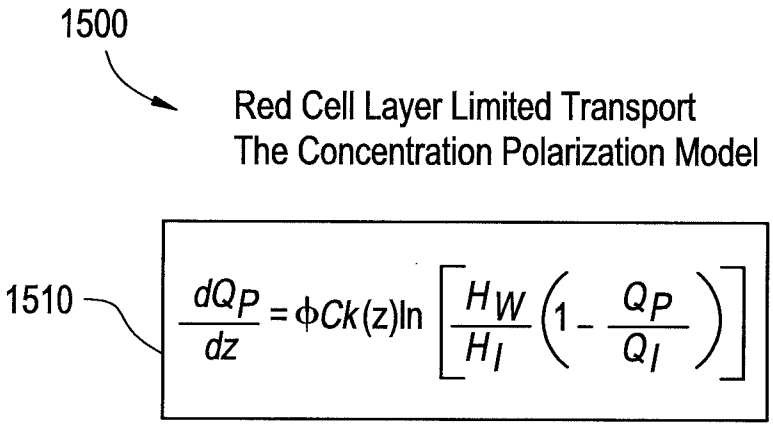

Transmembrane Pressure, ΔP_{TM}
140
120
100
80
60
40
20
0
0
10
20
30
40
50
60
70
Plasma Flow Rate, Q_P
Red Cell Layer
Limited Transport
Blood, HCT = 38
Membrane Limited
Transport
Plasma
Saline

FIG. 14



The mass transfer coefficient, *k*, varies from inlet to outlet and the cumulative plasma flow rate is obtained by integrating along the length, *z*, of the device.

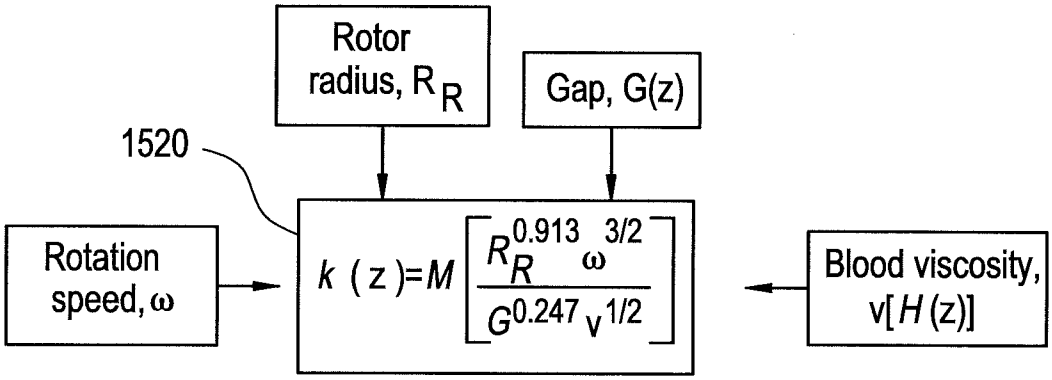


FIG. 15