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BLOOD SEPARATION METHOD

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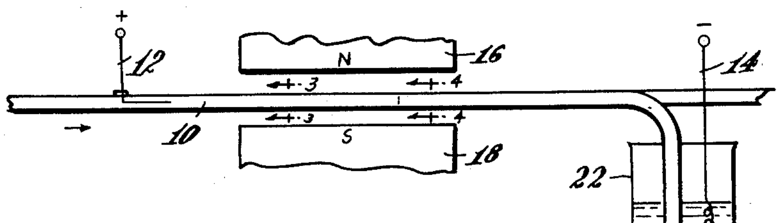

Fig. 1

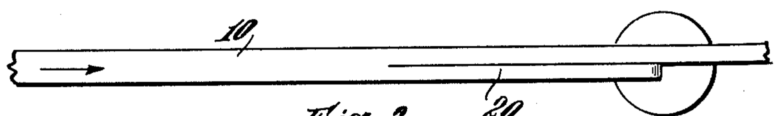

Fig. 2

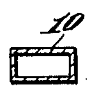

Fig. 3

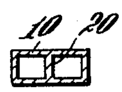

Fig. 4

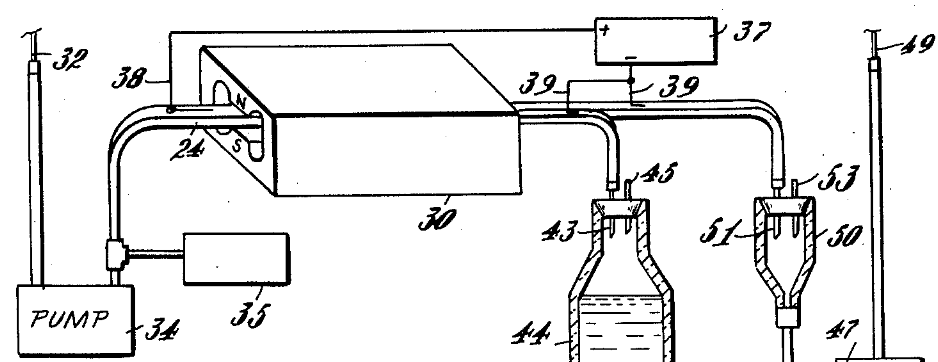

Fig. 5

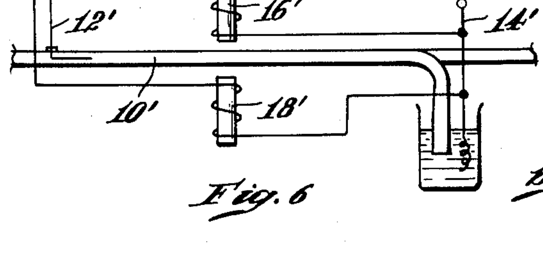

Fig. 6

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BLOOD SEPARATION METHOD

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This invention relates to a method of separating the differentially conductive components of a non-homogeneous mixture, and involves more particularly a method for continuously fractionating whole blood and returning the unneeded components to the donor simultaneously with the removal of the whole blood. This application is a continuation-in-part of copending application Serial No. 159,510, filed December 15, 1961 and entitled Blood Separation Method, now abandoned.

In many instances, only one of the components of a donor's blood is actually needed, and the unneeded fraction is often wasted or is only marginally useful. A more effective use of a donor's capabilities can be made if the unneeded components of his blood can be returned to him. Using conventional techniques this return would be cumbersome and expensive or unsafe. Typically, a substantial quantity of whole blood would have to be completely removed and processed as a unit. Then the unneeded component could be returned. For safety's sake a cross-matching of blood types would have to be performed to reduce the danger of an incompatible retransfusion reaction. For economic reasons this method is impractical.

Accordingly, objects of the present invention are to provide a method for continuously separating the components of whole blood simultaneously with its removal from the donor whereby the unneeded component can be conveniently and continuously returned to the donor. Further objects are to provide such a method which can be simply performed, which effects a usefully high degree of separation, which minimizes the total quantity of blood ever removed from the donor, which insures that the blood components returned to a donor are his own, and which permits an increased quantity of the desired blood component to be obtained from a given donor.

Still further objects are to provide apparatus for the practice of the above-described method which is simple and reliable in operation, which is easily cleaned, and which is relatively inexpensive.

The invention makes use of the difference in the electrical conductivity of the various blood components to effect their separation. In a broad aspect the invention contemplates a method of separating the differentially conductive components of a non-homogeneous mixture by passing said mixture along a relatively narrow, extended flow path, passsing an electric current along the flow in a portion of the path, applying to the flow in said portion a strong magnetic field which is transverse to the path, the vector cross product of the magnetic field and the electric current flow being always in the same direction with regard to any given point along said portion of said path, and dividing the flow at a point adjacent the downstream end of said portion along a plane of division extending parallel to the magnetic flux of the field, whereby each part of the divided flow is relatively enriched in one of the mixture components.

The invention may be more completely understood from the following detailed description, reference being had to the accompanying drawings in which

FIG. 1 is a side elevation of a simplified blood-fractionating apparatus;

FIG. 2 is a plan view of the blood flow tube of FIG. 1;

FIG. 3 is a section on the line 3—3 of FIG. 1;

FIG. 4 is a section on the line 4—4 of FIG. 1;

FIG. 5 is a diagrammatic illustration of a blood fractionating system; and

FIG. 6 is a view like FIG. 1 showing a modification.

Referring now to FIG. 1 blood is caused to flow slowly from left to right along the tube 10 of a rectangular cross section. Near the ends of the tube as shown are electrodes 12 and 14 for connection to positive and negative sources of electric current respectively. A portion of the blood flow in the tubing between the two electrodes is subjected to a transverse magnetic field created by the magnetic pole pieces 16 and 18. At a point near the downstream end of this magnetically influenced portion of the flow, the tubing 10 is divided into two flow paths by a septum 20, one portion of the flow being collected in the beaker 22.

This apparatus operates in the following manner. The cellular components of whole blood have a different electrical conductivity than the plasma. Typically the conductivity of the cells is about one-tenth that of the plasma. Accordingly if a current is passed through a column of whole blood the current density is not uniform across the column. Rather the current is concentrated in the plasma and tends to avoid passing through the cellular components. If the blood column is also subjected to a magnetic field which is transverse the current flow a pressure gradient will be developed across the plasma which is different than that developed across each of the individual cells. This difference in pressure gradient will result in a net relative force exerted between the cells and the plasma tending to drive each in an opposite direction across the width of the column transversely of the magnetic field. The speed at which relative movement takes place is governed not only by the intensities of the electric current and the magnetic field but also by the viscosity of the plasma and the consequent drag exerted upon the movement of the cells. Given sufficient time, however, an appreciable separation and concentration of each of the components will be accomplished. If the blood in the column is flowing along the length of the column a permanent separation of the components may be achieved by introducing a septum for dividing the flow into two distinct paths.

It will be apparent to those skilled in the art that it is also possible to use an alternating electric current for the separation process if the magnetic field is alternated in phase with the current. If this is done, the vector cross product of the magnetic field and the current flow is always in the same direction with regard to any given fluid particle and the separation will proceed in the same direction during both half cycles of the alternation period. This is illustrated in FIG. 6 where corresponding parts are correspondingly designated.

FIG. 5 shows a complete blood separation system incorporating provision for continuously returning the unneeded blood fraction to the donor. In this system whole blood is taken from a donor by means of a needle 32 and is driven by the pump 34 through the separator tubing 24 which passes through the magnet 30, electrodes 38 and 39 again being inserted into the upstream and the two downstream parts of the blood flow respectively and connected to a source of electric current 37. A suitable anti-coagulant or preservative solution may be added to the flow as from the container 35. The desired blood fraction is directed by means of a drip tube 43 into a bottle 44 where it is collected and held for use. The unneeded blood fraction is driven by a second pump 47 back to the donor through a second needle 49. Interposed in the path of this returned blood flow is a pressure equalizing vessel 50 into which the blood flow is introduced by a drip tube 51 and which is vented to the atmosphere through the tube 53. The bottle 44 is likewise vented to the atmosphere through a tube 45 and the ends of the two drip tubes **43** and **51** are positioned at the same vertical level. In this way, the back pressures on the two halves of the divided blood flow are equalized and the flow of blood immediately adjacent the leading edge of the septum will tend to remain laminar and this will not disturb the separated relationship of the blood components. While a straight separator tube has again been shown it should of course be understood that other configurations might be used in which the flow path reverses direction so as to make efficient use of the available magnetic field. A spiral is one such configuration. In any configuration, it is important that the magnetic field be as uniform as possible across the width of the flow path so that electromagnetically induced convection is avoided, such convection tending to remix the blood components.

A further increase in the degree of separation obtained may be accomplished by causing the cellular components of the blood to clump together. Clumping causes each group of blood cells to move as a single unit thereby reducing the viscous drag on the unit in relation to the separating force available. One compound which may be added to the upstream blood flow, for example at the pump **34**, and which will effect this clumping is glycerol pectate.

While a single stage of separation will effect such a degree of separation that the extracted blood is usefully enriched in the desired fraction and so that the amount of the desired fraction which may be obtained from a given donor is markedly increased, an even finer degree of separation can be obtained by connecting a plurality of separating units in series and then retaining only the desired component obtained from the last stage, all other fractions being returned to the donor. The advantages of higher concentration and increased donor capacity are however somewhat offset by increased costs so that typically it is economically preferable to use but a single stage of separation according to the invention thereby permittting a substantial quantity of the unneeded component to be returned to the donor and then to complete the separation to the degree desired in a separate process.

It should be understood that this disclosure is for the purpose of illustration only and that the present invention includes all modifications and equivalents falling within the scope of the appended claims.

We claim:

1. The method of separating the differentially conductive components of a non-homogeneous mixture, comprising passing said mixture along a relatively narrow and extended flow path, passing an electric current through the flow along a portion of said path, applying to the flow in said portion a strong magnetic field transversely of said path, the vector cross product of the magnetic field and the electric current flow being always in the same direction with regard to the direction of mixture flow at any given point along said portion of said path, and dividing the flow at a point adjacent the downstream end of said portion along a plane of division extending substantially parallel to the magnetic flux lines of said field whereby each part of the divided flow is relatively enriched in one of the mixture's components.

2. The method of fractionating whole blood comprising as continuous processes causing the blood to flow along an elongate flow path, passing an electric current through the flow along a portion of said path, applying to the flow in said portion a strong magnetic field transversely of said path, the vector cross product of the magnetic field and the electric current flow being always in the same direction with regard to the direction of blood flow at any given point along said portion of said path, and dividing the flow at a point adjacent the downstream end of said portion along a plane of division extending parallel to the magnetic flux lines whereby each part of the flow is relatively enriched in one of the blood's components.

3. The method of obtaining blood separation products from a donor patient comprising as continuous processes drawing a flow of whole blood from said patient, passing an electric current along a portion of the flow path, subjecting said portion of the flow to a strong transverse magnetic field, the vector cross product of the magnetic field and the electric current flow being always in the same direction with regard to the direction of blood flow at any given point along said portion of said path, dividing said flow into two paths at a point adjacent the downflow end of said portion along a plane of division extending parallel to the magnetic flux lines, and returning the flow passing along one of said paths to said patient's circulatory system whereby the flow along the other of said paths contains a concentration of the desired blood separation product and can be retained independently of the unwanted blood components which are continuously returned to the donor patient.

4. The method of separating the differentially conductive components of a non-homogeneous mixture, comprising passing said mixture along a reversing flow path, passing an electric current along the flow in a portion of said path, applying to the flow in said portion a magnetic field which is substantially transverse to said path throughout said portion, the vector cross product of the magnetic field and the electric current flow being always in the same direction with regard to the direction of mixture flow at any given point along said portion of said path, dividing the flow at a point adjacent the downstream end of said portion along a plane of division extending substantially parallel to the magnetic flux whereby each part of the flow is relatively enriched in one of the mixture's components.

5. Apparatus for continuously separating the differentially conductive components of a non-homogeneous fluid mixture comprising a relatively non-conducting tube, means for producing a flow of said mixture through said tube, means for passing an electric current through a flow of the mixture in said tube, means for applying a magnetic field across said tube which is transverse said tube throughout its length such that the vector cross product of the magnetic field and the electric current flow are always in the same direction with regard to the direction of fluid mixture flow at any given point along said portion of said path, and septum means within said tube for dividing a flow through said tube into two paths along a plane of division extending substantially parallel to the flux of the magnetic field.

6. The method of fractionating whole blood comprising as continuous processes causing the blood to flow along an elongate flow path, passing a unidirectional electric current through the flow along a portion of said path, applying to the flow in said portion a strong unidirectional magnetic field transversely of said path, and dividing the flow at a point adjacent the downstream end of said portion along a line of division extending parallel to the magnetic flux lines whereby each part of the flow is relatively enriched in one of the blood's components.

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