March 27, 1951 C. F. HALL 2,546,186

CONVECTION-COMPENSATING CENTRIFUGE

Filed March 11, 1947 3 Sheets-Sheet 1

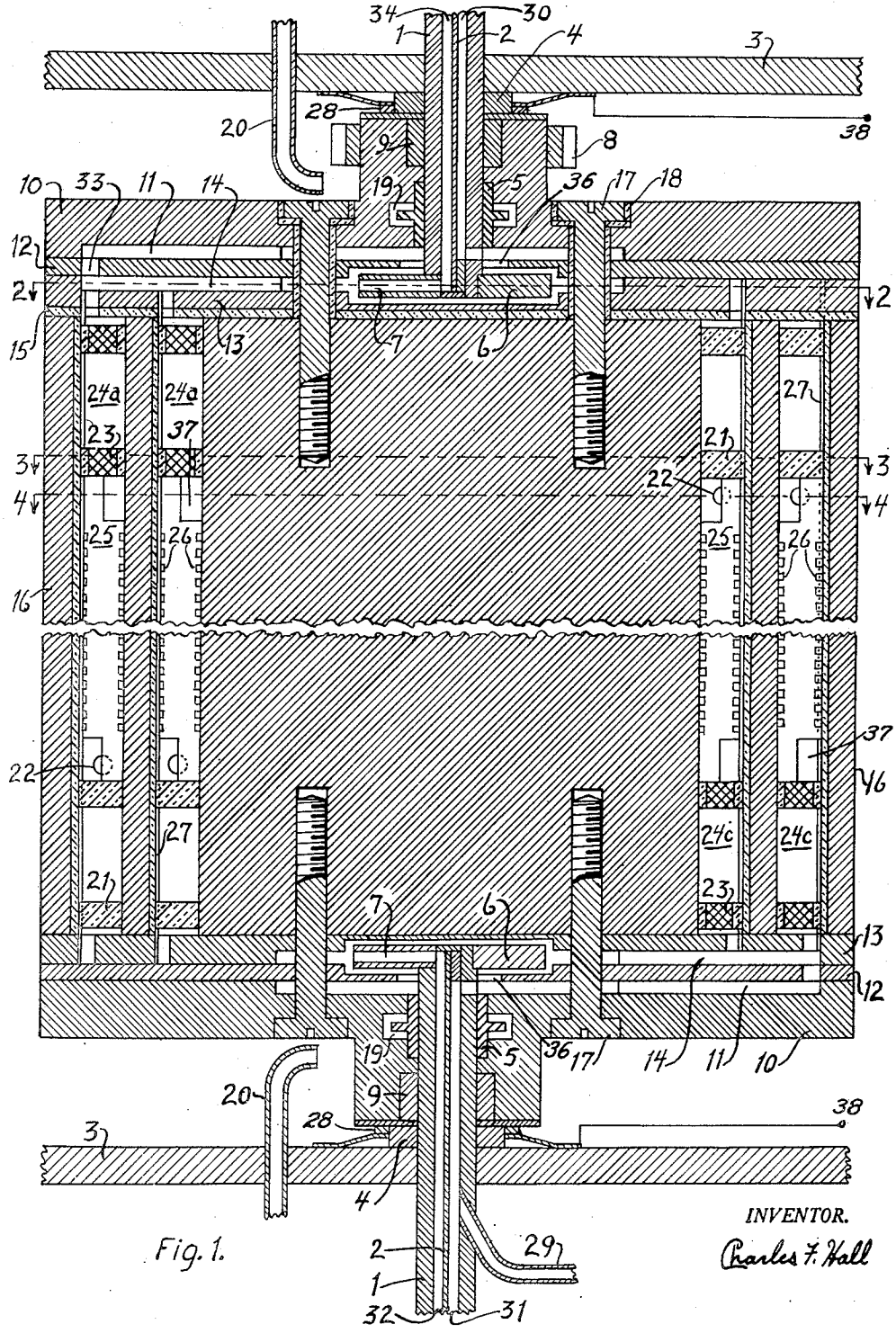


Fig. 1.

INVENTOR.

Charles F. Hall

March 27, 1951 C. F. HALL 2,546,186

CONVECTION-COMPENSATING CENTRIFUGE

Filed March 11, 1947 3 Sheets-Sheet 2

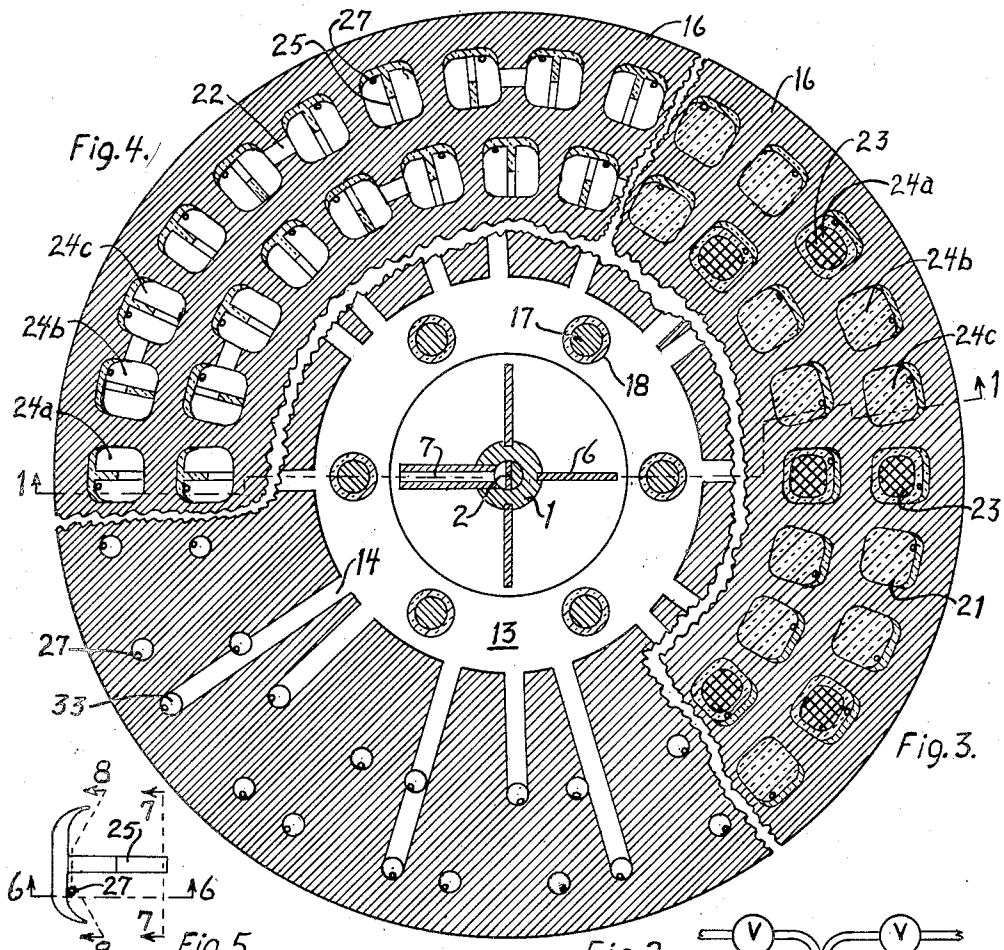


Fig. 4.

Fig. 3.

Fig. 5.

Fig. 2.

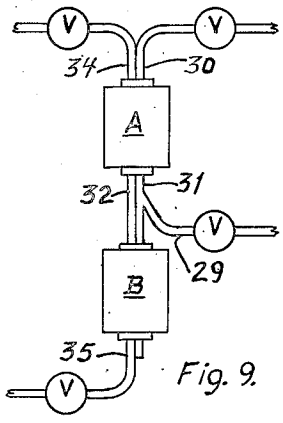


Fig. 9.

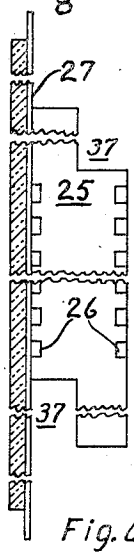


Fig. 6.

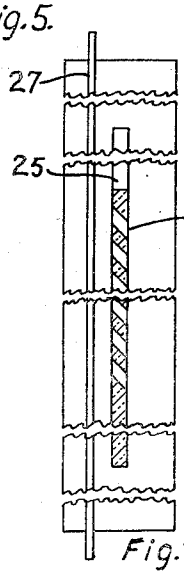


Fig. 7.

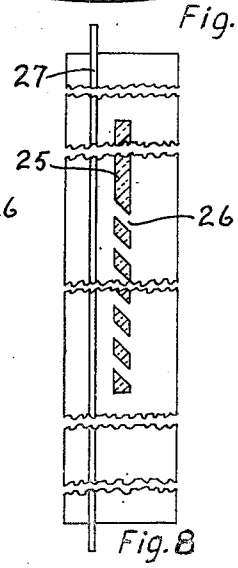


Fig. 8

INVENTOR.

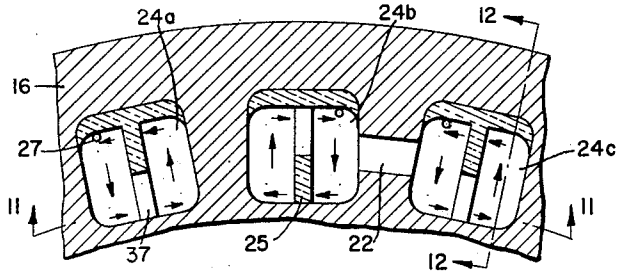
Charles F. Hall

March 27, 1951 C. F. HALL 2,546,186

CONVECTION-COMPENSATING CENTRIFUGE

Filed March 11, 1947 3 Sheets-Sheet 3

FIG. 10



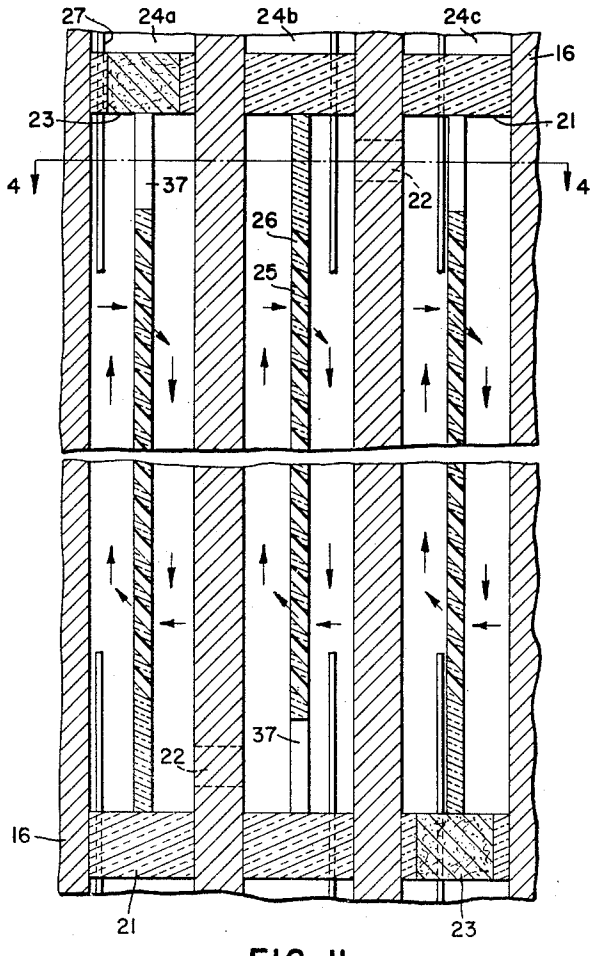


FIG. 11

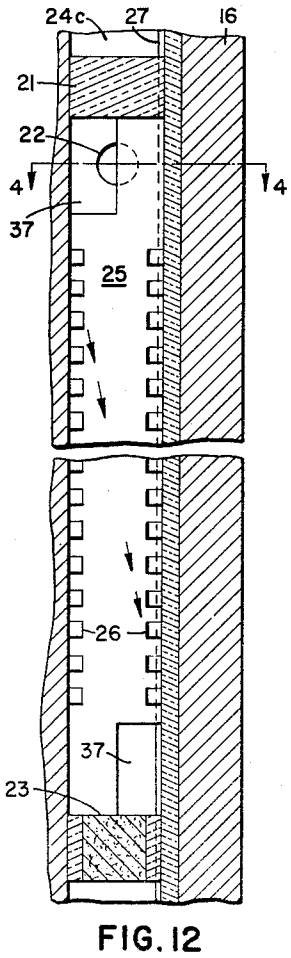


FIG. 12

INVENTOR

Charles F. Hall

Patented Mar. 27, 1951 2,546,186

UNITED STATES PATENT OFFICE

2,546,186

CONVECTION-COMPENSATING CENTRIFUGE

Charles F. Hall, Berkeley, Calif.

Application March 11, 1947, Serial No. 733,788

6 Claims. (Cl. 233—1)

1

My invention is a continuous flow, cross current, "convection-compensating centrifuge," in which an axial separation of fluid constituents of different mass is accomplished by means of adjacent oppositely flowing component axial currents having cross component currents which flow predominantly centrifugal across one axial current and flow predominantly centripetal across the opposite axial current. The axial separation is thus a function of centrifugal sedimentation velocities of the constituents, is independent of maintaining a state of centrifugal enrichment between axial currents, and is maintained by cross currents of ample magnitude; consequently separation is not seriously defected by thermal or mechanical irregularities of operation. And since separation takes place in an axial direction the distance through which separation takes place may be extended to provide a large separation factor at high resolving power; for separation of isotopes and other molecular or sub-molecular particles. Furthermore, the freedom from remixing defects allows use of a back wash or counter-current for continuous flow separation of proteins, virus, and other colloidal particles suspended in a fluid.

This application relates to my prior copending patent applications for Convection-Compensating Centrifuge, Serial No. 583,331, filed March 17, 1945 (now abandoned); Serial No. 624,761, filed October 26, 1945, now abandoned; Serial No. 654,753, filed March 15, 1946, now abandoned; and Serial No. 685,393, filed July 22, 1946. In addition thereto it shows a circuit diagram for two centrifuges employing a back wash current for separation of different colloidal particles of special value in biochemistry. And it shows a rotor having two concentric rings of series-parallel connected flues; and a new type of centrifugal mixing and circulating system to feed the flues.

Throughout the specification and claims the term "axial" or "axially" is used to denote a direction parallel or componently parallel to the axis of the centrifuge rotor; thus the expression "axially inclined passages" designates passages that are inclined to provide a component of fluid flow in a direction that is parallel to the axis; and the term "axial separation" designates a separation or enrichment of separable constituents that takes place in a direction that is parallel to the axis. The term "centripetal" is used to denote a direction radially inward toward the axis of the rotor. The term "centrifugal" is used to denote a direction radially outward from the axis of the rotor. And the term "circumferential" is used to denote a direction extending through an arc concentric to the circumference of the rotor.

The word "radially" is used in its broadest sense to denote radii extending as components of

2

centrifugal force. The term "centripetal cross current" is used to denote a radially inward component of current that crosses a component axial current. The term "centrifugal cross current" is used to denote a radially outward component of current that crosses a component axial current. The term "axial current" is used to denote component axial current.

In the accompanying drawings: Fig. 1 is a horizontal longitudinal section of the device, sectioned on the line 1, 1, Fig. 2, Fig. 3, and Fig. 4. Fig. 2 is a segment sectioned on the line 2, 2, Fig. 1. Fig. 3 is a segment sectioned on the line 3, 3, Fig. 1. Fig. 4 is a segment sectioned on the line 4, 4, Fig. 1. Fig. 5 is an enlarged end view of one of the baffle members. Fig. 6 is a section on the line 6, 6, Fig. 5. Fig. 7 is a section on the line 7, 7, Fig. 5. Fig. 8 is a section on the line 8, 8, Fig. 5. And Fig. 9 is a schematic circuit diagram for two centrifuges connected for employing a back wash current separation. Fig. 10 is an enlarged, broken segment of the rotor sectioned on line 4, 4, Figs. 1, 11, 12; it shows arrows to indicate the flow of fluid around each baffle, especially showing centrifugal and centripetal cross currents in the flues 24*a*, 24*b*, 24*c*. Fig. 11 is a broken section through the group of flues 24*a*, 24*b*, 24*c*, taken on a circumferential surface through the rotor on the line 11, 11, Fig. 10, and showing the baffles sectioned on the line 7, 7, Fig. 5, and midlengths of the wires 27 are broken away; it shows arrows to indicate the flow of fluid around each baffle, especially showing axial currents. Fig. 12 is a section on the line 12, 12, Fig. 10; it shows arrows to indicate a resultant current on one side of a baffle. In both Figs. 11 and 12 the short arrows indicate currents in the vicinity of a radially outer edge of a baffle; and the long arrows indicate currents in the vicinity of a radially inner edge of a baffle. Similar numerals refer to similar parts throughout the drawings.

The tubular stationary axles 1 are each divided into two internal ducts by the partitions 2. They are attached to the stationary beams 3, to the stationary disks 4, to the smooth surfaced sleeve gaskets 5, to the stationary vanes 6, and to the stationary radial extension tubes 7.

The rotor is driven by a gear or turbine drive wheel 8, and it revolves on the bearings 9. Each of the two rotor hub disks 10 are provided with internal radial channels 11. Each hub disk is hermetically cemented to a partition disk 12 hermetically cemented to a radially channelled disk 13 provided with radial channels 14. The outer end of each radial channel 11 is connected to the outer end of each corresponding radial channel 14 by a hole 33 and at the center the channels are connected through a hole 36 in the center of each disk 12, Figs. 1 and 2. At one end of the rotor the inlet duct 30 connects with

radial channels 11, and the outlet duct 34 connects through an extension tube 7 with radial channels 14. At the other end of the rotor the inlet duct 31 connects with radial channels 11, and the outlet duct 32 connects through an extension tube 7 with radial channels 14. At one end of the rotor, the disk 13 is hermetically cemented to the electrically insulative non-breakable glass disk 15 which is hermetically cemented to the rotor mid-piece 16; and at the other end of the rotor the disk 13 is hermetically cemented to the rotor mid-piece. The facings between the rotor disks must be smooth and the hermetical seals of cement must be thin so as not to be dislodged by centrifugal force. All of the rotor disks are bolted to the rotor mid-piece by means of the bolts 17. The bolts at one end of the rotor are electrically insulated by the non-breakable glass sleeves 18.

The annular channels 19 are filled with a suitable liquid to provide centrifugal liquid seals around the annular flanges of the sleeve gaskets 5; they are filled by way of screw plugged holes not shown.

Heating at the bearings is roughly equalized, to provide a fairly uniform temperature throughout the rotor mid-length, by a cooling fluid which is ejected onto the rotor hub disks by way of the stationary jets 20.

The rotor mid-piece is longitudinally perforated to provide axial flues through which constituents of the fluid content are axially separated. Any desired odd number of the axial flues may be connected in series by means of the plugs 21 and the connecting holes 22; thereby providing a single continuous series flue having an effective length which is some odd number of times greater than the effective mid-length of the rotor. Or if the rotor is long enough the plugs 21 and the holes 22 may be omitted to provide a parallel connection of flues.

Cemented in the open ends of each group of series connected flues are the diffusion plugs 23; which may each be made of tightly packed fiber glass cloth cemented in a peripherial plastic sleeve. They should be made so that their length and open area limits diffusion in each flue to approximately that of the volume of fluid being separated through each flue. In this way, undesired interconvection currents, between parallel connected groups of flues, are kept negligibly small. If the flues are all connected in series then the diffusion plugs 23 may be omitted. As shown in the drawings the flues are connected in series-parallel in groups of three series connected flues 24*a*, 24*b*, and 24*c*.

Within each flue and passing through or around a radially outer and a radially inner part of each baffle are rows of closely spaced passages 26; said passages being in full or in part axially inclined to direct cross current circulation in a componently axial direction so as to produce axial currents, see Figs. 1, 4, 5, 6, 7, 8, 10, 11, 12. The passages may be adjacent to the edges or intermediate to the edges of each baffle or they may be part of any member within a flue, but they must be separated by a radial distance in the direction of centrifugal force, they must be closely spaced in the axial direction, and they must be at least in part axially inclined. The passages may be rectangular holes as shown or they may be molded in the shape of converging nozzles. In the ends of each baffle there are diagonally opposite openings 37 through which the axial currents circulate. The series connecting flues 24*b* have plugs 21 at both ends and the direction of separation is reversed therein; hence the position of, as shown in Fig. 4, the diagonally opposite openings 37 is transposed in the flues 24*b*.

Each baffle is molded, or otherwise attached to a cross element so that the whole baffle member has the shape of a T, as shown; and the whole member should be made of glass or some other suitable heat insulative material. Each baffle member carries an electrically heated metal strip or wire 27 both ends of which are electrically connected to the disks 12 and thus electrically connected through the stationary slip rings 28 and through the diagrammatically shown electrical connections 38 to a controlled source of electricity. If gases or vapors at reduced pressure are to be separated, then the wires 27 should be disconnected and broken away from the disk 12 at the end of the rotor mid-piece which is not electrically insulated therefrom, and a high enough voltage should be applied to the wires to produce a glow discharge throughout the length of each flue; thus directly heating the gas on one side of each baffle.

By means of the cooling jets 20 and the heating wires 27, heat distribution is controlled so that circumferential temperature gradients exceed axial temperature gradients throughout the fluid content in the mid-length of each flue. Due to centrifugal head of pressure and circumferential temperature gradients, currents flow around each baffle and through the axially inclined passages 26, see Figs. 10, 11, 12. The open area of the passages 26, through which the currents flow, is shown in Figs. 1, 6, 12. For a full length flue, for example in a rotor three or four feet long, the total open area of all of the passages 26 is greater than the cross sectional area of a flue as seen in Figs. 4 and 10; also the axial current velocity as produced by the axial incline of the passages 26 is less than the velocity through the passages; thus the volume of fluid circulating as cross currents exceeds the volume of fluid circulating as axial currents and a state of axial separation is maintained.

Furthermore the open area of the passages 26 is less than the cross sectional area of a flue as seen in the sectional view, Fig. 11; thus the velocity of the cross currents through this section is less than the velocity of the currents through the passages and consequently the velocity of the axial currents, as a function of the currents through the passages, is greater than the velocity of the cross currents and so an amplified separation factor is attained.

To provide the most effective circumferential temperature gradients, the position of the electrically heated wires 27 is transposed in every other flue, as shown in Figs. 3, 4, 10, and 11. If the axial inclination of the passages 26 is unchanged, then this transposition reverses the direction of inclination of the passages toward their heated wire which reverses the direction of the axial circulation of fluid and reverses the direction of separation. So for each transposition in a series connection of flues: the inclination of the passages, toward their heated wire, is reversed. But for a parallel connection of flues: the passages must always have the same inclination toward their heated wire.

To provide the most effective centrifugal temperature gradient, for centrifugal heat dissipation, the electrically heated wires in the central ring of flues should be heated to a higher tem-

perature than the electrically heated wires in the outer ring of flues.

Considering the flow of fluid in flue **24***c*, Figs. 1, 4, 10, 11, 12: due to centrifugal head of pressure in conjunction with circumferential temperature gradients, fluid passes from the unheated side of the flue to the heated side through axially inclined passages **26** along the radially outer edges of a baffle **25**, and it passes from the heated side to the unheated side through axially inclined passages **26** along the radially inner edge of the baffle. In passing through the axially inclined passages it is given an axial circulation; thus for flue **24***c*, as seen in Fig. 11, there is a downward axial current on the unheated side and an upward axial current on the heated side; and as seen in Fig. 10, there is a centrifugal cross current on the same side as the downward axial current and a centripetal cross current on the same side as the upward axial current. Within the fluid are both heavy and light weight separable constituents which are affected by centrifugal force and for the illustration given herein it is considered that the heavier constituents have faster centrifugal sedimentation velocities than the lighter constituents. For separation of constituents such as molecules or colloidal particles the velocity of the cross currents is greater than the centrifugal sedimentation velocities of the constituents; and so the cross currents carry the constituents around the baffle. Due to the differences in centrifugal sedimentation velocities, the lighter constituents, as carried in the centrifugal cross current, travel slower than the heavier constituents and thus the lighter constituents are enriched within the unheated axial current and are displaced and axially enriched in the direction of said unheated axial current. But in the centripetal cross current the heavier constituents travel slower than the lighter constituents and thus the heavier constituents are enriched within the heated axial current and are displaced and axially enriched in the direction of said heated axial current. The axial enrichment is dependent upon averaged differences in the summation of the centrifugal and centripetal cross currents and sedimentation velocities as circumferentially maintained by the baffle in each flue. It is not dependent upon maintaining a state of centrifugal enrichment and so it is not adversely affected by centrifugal and centripetal circulation of the fluid which destroys or defects the centrifugal enrichment necessary in other types of centrifuges.

The flues **24***a*, **24***b*, **24***c*, are connected in series by means of the holes **22**; the direction of separation is reversed in the flue **24***b*; and so from this group of series connected flues the axial enrichment of lighter constituents diffuses through the porous plug **23** in the end of the flue **24***c* and out of the flue into the channels **11** at one end of the centrifuge, and the axial enrichment of heavier constituents diffuses through the porous plug **23** in the end of the flue **24***a* and out of the flue into the channels **11** at the opposite end of the centrifuge.

In operation: two centrifuges A and B, Fig. 9, are connected in series. A thickened concentrate of particles is fed through the Y connection duct **29**, Figs. 1 and 9, and the fluid free of particles is fed, as a back wash current, through the duct **30**. By way of the two ducts **31** and **32**, the fluid mixture is continuously circulated and mixed, between the centrifuges A and B, by means of the difference in centrifugal pressures established by the stationary radial extension tubes **7**. In the end compartments of both centrifuges the stationary vanes **6** serve to produce a difference in centrifugal pressure which circulates the mixture through the radial channels **11** and **14**; thus providing centrifugal mixing and uniformly distributing the mixture to the ends of the flues which are connected to the radial channels through the diffusion plugs **23**, and through the holes **33**. If for example the specific gravity of all the particles is greater than the specific gravity of the fluid: then within the flues the separation of particles from the fluid is directed toward the outlet duct **34**, that is against the back wash current which flows out through the outlet duct **35**. Thus by suitable control of the valves V, the heavier particles may be drawn off from the outlet duct **34** and the lighter particles may be drawn off from the outlet duct **35**. The centrifuge A is to separate the heavier constituents from the mixture circulating in the ducts **31** and **32**; and the centrifuge B is to separate the lighter constituents from the mixture circulating in the ducts **31** and **32**. At one end of each of the two centrifuges the duct **31** connects to the duct **29** and connects the outlet channels of centrifuge B to the inlet channels of centrifuge A; and the duct **32** connects the outlet channels of centrifuge A to the inlet channels of centrifuge B. At the opposite end of centrifuge A the duct **30** connects to the inlet channels of centrifuge A, and duct **34** connects to the outlet channels of centrifuge A. At the opposite end of centrifuge B the duct **35** connects to the outlet channels of centrifuge B, and the duct connecting to the inlet channels, of centrifuge B, is plugged off or omitted.

The separation velocity of the particles varies directly as their difference in molecular weights, that is directly as the resolving power, and separation is not dependent upon maintaining a critical state of centrifugal enrichment, hence control is not excessively critical even for high resolving powers.

For separation of a mixture of fluids it is not necessary to employ the back wash current principle of separation; although the holdover time before starting to draw off minority constituents may be reduced if this principle is employed.

There are a number of modifications of my invention. For instance the flues may be extended circumferentially, spirally, helically, or on a conical incline. But such modifications do not depart from the principles illustrated in the drawings and specification and set forth in the following claims.

I claim:

1. In a centrifuge a rotor comprising a cylinder perforated by a number of axial flues through which a fluid and separable constituents are circulated, a baffle circumferentially dividing each flue, in each baffle a multiplicity of closely spaced axially inclined passages passing through a radially outer part of the baffle and a corresponding multiplicity of closely spaced axially inclined passages passing through a radially inner part of the baffle, on one side of each baffle an axially extending thermal element producing convectional circulation of fluid through the axially inclined passages said inclined passages being so positioned that said circulation produces oppositely directed component axial currents on circumferentially opposite sides of each baffle and produces component cross currents which flow predominantly centrifugal across one component axial current and flow predominantly centripetal

across the oppositely directed component axial current, at opposite ends of the rotor a number of radial channels connecting the ends of the flues to stationary inlet and outlet ducts and stationary vanes and stationary radial extension tubes circulating the fluid through the radial channels and through the ducts, bearings to support the rotor and means to cool the bearings and minimize axial temperature gradients through the rotor, all combining to provide a maintained axially amplified enrichment of constituents maintained by cross currents and dependent upon a maintained circumferential enrichment of constituents as maintained by the baffle within each flue.

2. In a centrifuge the combination of axially extending flues circumferentially divided by axially and radially extending baffles in which a multiplicity of closely spaced axially inclined passages pass through radially outer and radially inner portions of the baffles, means for circulating fluid through said axially inclined passages said passages being so positioned as to provide centrifugal and centripetal cross currents and axial currents for axial separation of constituents within said flues, means for supplying fluid to said flues and means for withdrawing fluid from said flues adjacent the ends thereof.

3. In a centrifuge a rotor comprising a cylinder perforated by a number of axial flues through which a fluid and separable constituents are circulated, a baffle circumferentially dividing each flue, in each baffle a multiplicity of closely spaced axially inclined passages passing through a radially outer part of the baffle and a corresponding multiplicity of closely spaced axially inclined passages passing through a radially inner part of the baffle, electrically insulated therefrom and supported by the radially outer wall of each flue and on one side of each baffle an axially extending electrically heated strip electrically connected to slip-rings at the ends of the rotor and providing an electric thermal element in each flue, said passages being so positioned that said thermal element produces radial circulation about said baffle and axial circulation in opposite directions on opposite sides of baffles, thereby producing enrichment of said constituents axially of said flues, means for supplying fluid to said flues, and means for withdrawing fluid from said flues adjacent the ends thereof.

4. In a centrifuge, in combination, a rotor comprising a cylinder perforated by a number of axial flues through which a fluid and separable constituents are circulated, a baffle circumferentially dividing each flue, in each baffle a multiplicity of closely spaced axially inclined passages passing through a radially outer part of the baffle and a corresponding multiplicity of closely spaced axially inclined passages passing through a radially inner part of the baffle, on one side of each baffle an axially extended thermal element, at opposite ends of the flues holes and plugs to connect groups of flues in series and in each alternate flue of each series connected group a transposed thermal element to provide a reversal of separation within said alternate flue so that separation within each series group of flues is directed back and forth along the axial length of the rotor to extend the distance through which constituents are separated to improve purification of the separation, diffusion plugs in the ends of each group of series connected flues to prevent excessive circulation between these groups of flues and to thus allow a parallel connection of groups of flues to increase volume of separation as connected through radial channels and inlet and outlet ducts.

5. In a centrifuge rotor through which a fluid and separable constituents circulate, radially extended baffles to maintain adjacent oppositely flowing currents of fluid on circumferentially opposite sides of the baffles, a multiplicity of closely spaced passages located at radially outer and radially inner positions through which circulation of fluid passes the baffles, and an axial inclination of the passages to direct the currents in componently opposite axial directions on circumferentially opposite sides of the baffles, thermal elements being so positioned as to produce centrifugal and centripetal cross currents and to establish the circulation of fluid, at opposite ends of the centrifuge rotor channels to collect axial enrichment of the separable constituents and inlet and outlet ducts connected thereto.

6. A centrifuge circuit comprising a centrifuge A for separating heavier constituents from a fluid mixture and a centrifuge B for separating lighter constituents from a fluid mixture, both the centrifuges being of a structure as recited in claim 1; connecting to channels in one end of centrifuge A, a valve and inlet duct for fluid unmixed with constituents and a valve and outlet duct for fluid mixed with an enrichment of heavier constituents; connecting to channels in the opposite end of centrifuge A and connecting to channels in one end of centrifuge B and connecting to a Y connection duct and valve through which both heavier and lighter constituents are fed to the circuit, an outlet duct of centrifuge A connected to an inlet duct of centrifuge B and an inlet duct of centrifuge A connected to an outlet duct of centrifuge B; connecting to channels in the opposite end of centrifuge B a valve and outlet duct for fluid mixed with an enrichment of lighter constituents.

CHARLES F. HALL.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
Re. 21,168	Coutor	Aug. 1, 1939
507,442	Lentsch	Oct. 24, 1893
895,173	Ecaubert	Aug. 4, 1908
1,061,656	Black	May 13, 1913
1,126,247	Mason	Jan. 26, 1915
1,525,808	Hall	Feb. 10, 1925
1,700,928	Fawkes	Feb. 5, 1929
2,114,497	Kelling	Apr. 19, 1938
2,176,982	Thayer	Oct. 24, 1939
2,223,999	Miller	Dec. 3, 1940
2,258,594	Brewer	Oct. 14, 1941
2,286,157	Podbielniak	June 4, 1942
2,313,540	Hall	Mar. 9, 1943
2,394,357	Beese	Feb. 5, 1946
2,422,882	Bramley	June 24, 1947

OTHER REFERENCES

A general Account of the Development of Methods of Using Atomic Energy for Military Purposes—Smith, 1945. (Copy available in Div. 25, U. S. Patent Office.)