Oct. 31, 1967 E. G. PICKELS 3,350,002

CENTRIFUGE APPARATUS

Filed March 14, 1963

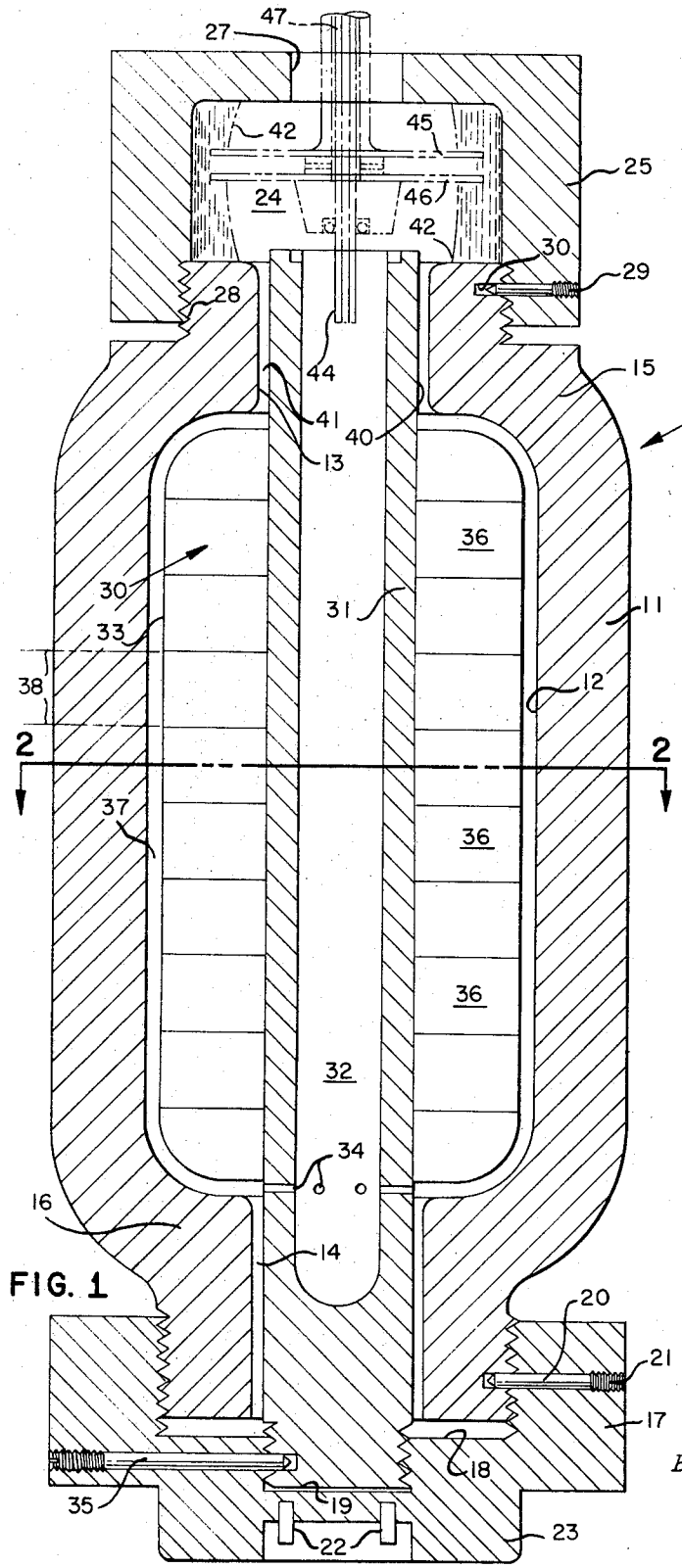


FIG. 1

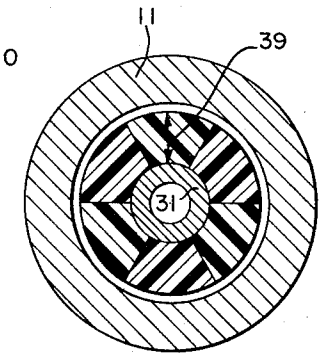


FIG. 2

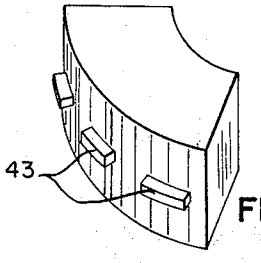


FIG. 3

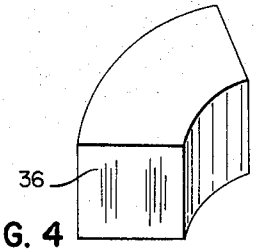


FIG. 4

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United States Patent Office 3,350,002 Patented Oct. 31, 1967

3,350,002

CENTRIFUGE APPARATUS

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Filed Mar. 14, 1963, Ser. No. 265,089
17 Claims. (Cl. 233—28)

This invention relates generally to centrifuge apparatus and more particularly to a rotor for such apparatus.

In prior continuous flow centrifuge apparatus, a rotor assembly is provided wherein sediment deposited by centrifugation is readily resuspended for further treatment or analysis. One rotor assembly includes a cylindrical core enclosed in a surrounding shell or bowl. For centrifugation operations the core is maintained concentrically fixed with respect to the bowl. An annular space is thereby defined between the core and the bowl to form a separating chamber having surfaces wherein deposited sediment accumulates. The accumulated sediment is resuspended after centrifugation.

A releasable axial sleeve is first removed so that the core is no longer held axially fixed with respect to the shell. The rotor is then filled with a suitable resuspension liquid, such as distilled water, plugged, and laid on its side. With its axis disposed horizontally, the rotor is rotated by suitable means. During this rotation, the core rides freely on the inner wall of the bowl to agitate the sediment whereby the latter is resuspended in the liquid.

It is a general object of the present invention to provide an improved rotor suitable for continuous flow centrifugation.

Another object of the invention is to provide a core means which is contractable under radially inwardly acting centripetal forces which are generated during centrifugation so that contraction of the core serves to form a separation chamber defined between the inner wall of the bowl and the outer periphery of the core means.

Another object of the invention is to provide a rotor assembly wherein the core is freed and expands after centrifugation whereby it can ride freely on the inner wall of the bowl during resuspension of deposited sediment.

It is a more specific object of the invention to provide a rotor assembly wherein during centrifugation the core is urged radially inwardly by centripetal forces to contract the perimeter of same and form a separation chamber and wherein withdrawal of these forces frees the core so that it can move into contact with the inner wall of the bowl during subsequent sediment-resuspension operations.

Still another object of the invention is to provide a rotor assembly having a free, segmented core wherein the segments have a predetermined specific gravity selected to cause the segments to move toward the axis of the rotor during centrifugation.

Another object of the invention is to provide a centrifuge rotor having a low hold-up volume.

These and other objects, features and advantages of the invention will be more readily apparent from the following detailed description of a preferred embodiment of the invention when taken in conjunction with the drawings in which:

FIGURE 1 shows a centrifuge rotor apparatus, in section, disposed for operation in a continuous flow centrifuge. For example, see United States Patent No. 3,073,517, granted Jan. 15, 1963, assigned to the assignee herein.

FIGURE 2 is a section of FIGURE 1 taken along the line 2—2 thereof and proportionately reduced.

FIGURE 3 is a diagrammatic perspective view showing a segment of the core shown in FIGURE 1.

FIGURE 4 shows another embodiment of a core segment.

In general, there is provided a centrifuge rotor assembly for both batch and continuous centrifugation of liquid sample and resuspension of sediment recovered from the centrifugation. The rotor assembly comprises a hollow bowl formed with an upwardly extending inner wall, and contains a core means mounted to be rotated with the bowl about a generally vertical axis. The perimeter of the core means contracts under urging of radially inwardly acting centripetal forces generated during centrifugation. This contraction of the core provides a separation chamber defined between the inner wall of the bowl and the outer periphery of the core means. Termination of centrifugation removes these forces from the core means to free it for movement into contact with the inner wall of the bowl. Resuspending the deposited sediment may then proceed immediately as the next step. The rotor assembly may further include fluid passage means forming a path for passing liquid sample continuously into and out of the separation chamber during centrifugation.

Centrifuge apparatus is shown in FIGURE 1. The parts in phantom lines represent parts as generally disclosed in my patent, referred to above. Portions of this structure are described further below.

In FIGURE 1 a rotor assembly **10** includes means forming a hollow bowl **11**. Bowl **11** is formed with an upwardly extending inner wall **12** which curves radially inwardly at both ends to form openings **13** and **14**, respectively. The surface of wall **12** merges with the surface of openings **13** and **14**.

Means are provided for mounting bowl **11** for rotation about its vertical axis during centrifugation. The mounting means may include an annular cap **17** formed with coaxially arranged threaded recesses **18** and **19**. Threads of recess **18** engage threads on the exterior of portion **16**. Bowl **11** can be locked with respect to cap **17** by suitable means such as the transverse pin **20** disposed in a hole **21** drilled through the side wall of the cap **17** and into portion **16**. Pin **20** can be secured in place either by a plug or by threads formed on its outer end.

In order to connect cap **17** for rotation with a rotor mounting element such as a stub shaft (not shown) there is provided a pair of downwardly projecting pins **22** adapted to be received in co-acting holes formed in such a mounting element. Pins **22** are located inside an axially depending sleeve **23** adapted to fit over the mounting element (not shown).

In continuous centrifugation, liquid sample can be supplied from a reservoir into a fluid feed or receiving chamber located near the axis of rotation. The liquid then passes radially outwardly to a separation chamber between the core and bowl. The outer wall of the separation chamber collects the sediment, and the remaining liquid then passes to a fluid removal chamber. The latter discharges to a suitable receiving vessel.

As disclosed herein, many of these functions are performed by a core assembly **30** within bowl **11** as now to be described.

Means forming part of core assembly **30** are provided for introducing fluid sample axially into the rotor assembly **10** from a supply vessel (not shown). Accordingly, a hollow center post **31** is disposed co-axially of bowl **11**. The interior of center post **31** forms a fluid feed chamber **32**. Chamber **32** is open at the upper end to receive fluid sample therein as supplied, for example, via a downwardly depending tubular shaped member **44**.

Fluid passage means forming a path for passing liquid sample out of chamber **32** is formed by transverse openings **34** disposed near the bottom of chamber **32**. Means are further provided whereby center post **31** is readily removable from bowl **11**. The bottom of post **31** is threadedly engaged in recess **19** and locked with respect

to cap **17** by suitable means such as the transversely extending pin **35**.

In general, core assembly **30** further includes a generally cylindrically-shaped, segmented core body **33** which loosely encircles center post **31**. Core body **33** is made up of a plurality of segments **36** such as shown in FIGURE 3 which are individually and collectively responsive to application of centripetal forces generated during centrifugation of liquid sample. These forces urge the segments toward the axis of the rotor. Thus, the perimeter of the core body contracts to form a separation chamber **37** of flow hold-up volumn. Chamber **37** accumulates sediment on its outer wall **12** during centrifugation. Chamber **37** is thus defined by the wall **12** and the peripheral surface of core body **33**.

More specifically, it will be noted that segments **36** of core body **33** are arranged in tiers stacked to rest loosely one upon the other. The tiers are defined between spaced planes **38** disposed transversely to the axis of rotor assembly **10**. Core body **33** is further separated, as shown in FIGURE 2, to provide a transverse cross section defining an annulus **39** separated into a plurality of generally pie-shaped portions. While the foregoing rather extensive segmental subdividing of the core body is preferred, it is to be understood from the operation as explained further below that the core body can be merely divided into vertically elongated segments formed only with the pieshaped cross section without separating same into tiers. Furthermore, it may be desirable to use some complete tiers together with some which are divided by radial separations. Where complete tiers are desired the bowl **11** can be made in two parts permitting each annulus to be inserted.

Segments **36** are made from suitable material, such as plastic, wherein the overall specific gravity of the segment is relatively low. Accordingly, they can be either solid or hollow. For effective operation the specific gravity of segments **36** should be less than the constituents of the liquid sample being centrifuged. Under these conditions segments **36** will "float" toward the axis of rotation, that is, they will be forced against center post **31** during centrifugation. As one example, using a liquid sample with a specific gravity of 1.3, the segments will float inwardly when prepared to have a specific gravity of 1.2. In this manner, under high speed rotation, separating chamber **37** is formed as shown in FIGURE 1.

Means are provided at the upper end of bowl **11** to form a fluid removal chamber **24**. One suitable arrangement can include a cup-shaped cap member **25** formed with an axial recess **26** and a co-axial opening **27** at the upper end thereof. A threaded portion **28** extends around the lower edge of recess **26** to engage threads formed around the exterior of portion **15**. A locking pin **29** extends into a transverse registration hole formed to extend into the threaded portion of bowl **11**. Fluid removal chamber **24** therefore has a smooth side wall continuous from wall **12** and opening **13** to facilitate removal of fluid from the rotor assembly.

The means shown in phantom lines serves to pump fluid sample from fluid removal chamber **24** in the manner described herein further below.

As noted above the wall of opening **13** merges with the surface of wall **12**. The exterior surface **40** of center post **31** extends into opening **13** to form a fluid passage **41** leading out of separating chamber **37** and into fluid removal chamber **24**.

From the foregoing it will be evident that the rotor assembly **10** is very simple to assemble. Cap **17** is screwed onto portion **16** of bowl **11** and locked in place by inserting pin **20**. Segments **36** are then dropped into bowl **11** and arranged in annular tiers as shown. Center post **31** is then fished axially down through bowl **11** and screwed into recess **19**. Pin **35** is inserted to lock center post **31** with respect to bowl **11**. Then, with the pump unit of the centrifuge in position (as shown in phantom lines), cap **25** is screwed onto the top of bowl **11** and locked in place by pin **29**.

Operation of the above rotor assembly is as follows. During centrifugation a sample to be separated is fed from a supply vessel (not shown) via tubular member **44** and into fluid feed chamber **32**. The fluid rides gently onto the vertical wall of chamber **32** under the influence of centrifugal force. Fluid feeds outwardly via passages **34** into the lower end of separating chamber **37**. Fluid progresses upwardly in separating chamber **37**, then inwardly, and again upwardly in passage **41** finally entering removal chamber **24**. While the fluid is in separating chamber **37**, sediment is deposited due to high centrifugal forces encountered.

Fluid in removal chamber **24** is removed by any suitable means. For example, the structure shown in the above-identified application includes a pump comprising merely a pair of spaced discs **45**, **46**. The pump operates in the following manner: when the rotor is operated at relatively high velocity, liquid sample within the rotor is urged outwardly by centrifugal force. The liquid rides against the outer wall of chamber **24** and forms a vertical wall of fluid, illustrated at **42** in FIGURE 1. The rotational velocity of the fluid between the plates **45**, **46** is reduced by frictional engagement with the plates. Consequently, the centrifugal force and accompanying pressure is reduced in this area. The higher pressure exerted by the remainder of the fluid in chamber **24**, which fluid is at full rotor rotational velocity, forces the sample inwardly between plates **45**, **46** and through an annular axial opening **47** formed in the vertically disposed tubular member **44**.

Chamber **24** is continuously replenished with liquid sample as follows. As sample is fed into fluid feed chamber **32**, the vertical wall of fluid therein will have a smaller diameter than the wall **42** of fluid in removal chamber **24**. As a result there will be a pressure difference which causes the fluid to flow continuously through the rotor. This difference in head is present because of frictional drag through passages **34**, **41** and separating chamber **37**. The incoming fluid entering chamber **32** displaces the "resident" fluid in the rotor in a direction toward removal chamber **24**.

During centrifugation, heavy particles are acted upon by centrifugal force and settle out packed against wall **12**. To recover the deposited sediment various procedures can be followed.

One method as explained above which has previously been followed is to remove a supporting part of the assembly which holds the core assembly fixed within the bowl. The core assembly can then ride freely upon the inner wall of the bowl when laid on its side. A fluid suitable for mixing with the sediment is introduced into the rotor and the rotor sealed by a plug. By placing the rotor on its side and rotating it, the core agitates the sediment from the inner wall of the bowl to resuspend it in the mixing fluid. As explained in the above-identified application the liquid in front of the core is pushed ahead of the rolling core. The core may also slip somewhat to give rise to a scraping action.

In the present apparatus the rotor assembly is automatically ready to resuspend sediment as soon as centrifugation has terminated.

If the above outlined procedure is followed, the rotor is removed from the centrifuge. A suitable mixing fluid is then poured into the rotor via opening **27** and a cork inserted. The rotor assembly can then be laid on its side and rotated, as by resting the same on rollers.

During rotation segments **36** are free to move into contact with inner wall **12** of bowl **11** so as to agitate the sediment. If desired, center post **31** can be unscrewed from recess **19** and left substantially in place so as to apply additional agitating weight to segments **36**. In this manner, the center post provides a readily releasable means for applying additional compressive force between core

body 33 and wall 12 when the rotor is conditioned horizontally for resuspension operation.

On the other hand, if suitable rollers are not readily available, the sediment can be resuspended merely by agitating center post 31 by hand in the presence of a suitable mixing liquid. Thus, segments 36 can be moved outwardly into scraping contact with wall 12. To enhance the scraping action, according to another embodiment of the invention, outwardly projecting scraping members 43 as shown in FIGURE 4 can be formed on the surfaces 44 of segments 36.

From the foregoing it will be evident that there has been provided a simplified centrifuge rotor apparatus wherein the core means is responsive to centripetal forces generated during centrifugation of liquid sample. Under these centripetal forces the segments "float" toward the axis of rotation so as to contract the perimeter of the core means. Subsequently, however, the core means is free upon withdrawal of these forces to move into contact with the inner wall of the bowl so as to aid in resuspending deposited sediment. It should also be noted that the hold-up volume, i.e. the volume between the fluid feed chamber and the fluid removal chamber is minimized.

I claim:

1. A centrifuge rotor assembly for centrifugation of liquid sample and resuspension of sediment recovered therefrom comprising a hollow bowl formed with an upwardly extending inner wall, a core body carried within said bowl and disposed about a vertical axis for centrifugation operations, said core body having a substantially cylindrical outer surface and being free to rotate independent of said hollow bowl, said core body comprising discrete segments contractable during centrifugation to provide a separation chamber for accumulating sediment, said separation chamber being defined by said inner wall of said bowl and said outer surface of said core body, and said core body being free upon termination of centrifugation to move toward said inner wall of said bowl and ride along said inner wall to remove said sediment therefrom for resuspending said sedment.

2. A centrifuge rotor assembly as defind in claim 1 further including fluid passage means for conducting liquid sample continuously into and out of said separation chamber during centrifugation.

3. A centrifuge rotor assembly for centrifugation of liquid sample and resuspension of sediment recovered therefrom comprising a hollow bowl formed with an upwardly extending inner wall, a core assembly including a core body carried within said bowl and disposed about a vertical axis for centrifugation operations, said core body being free to rotate independent of said hollow bowl, comprising discrete segments, and having a substantially cylindrical outer surface, said core body being subject to centripetal forces generated during centrifugation and acting radially inwardly to contract said outer surface of said core body to provide a separation chamber for accumulating said sediment, said chamber being defined by said inner wall of said bowl and said outer surface of said core body, and said core body being free upon withdrawal of said forces to move toward said inner wall of said bowl and ride along said inner wall in scraping contact to remove said sediment therefrom for resuspending said sediment.

4. A centrifuge rotor assembly as defined in claim 3 further including fluid passage means for conducting liquid sample continuously into and out of said separation chamber during centrifugation.

5. Centrifuge apparatus as defined in claim 3 wherein said core assembly further includes releasable means disposed in said core body for applying additional compressive force between said core body and said inner wall during said resuspension operation.

6. Centrifuge apparatus as defined in claim 5 wherein said releasable means includes a hollow center post disposed coaxially of said bowl, said post being open at one end to form a fluid feed chamber for receiving liquid sample, and a fluid passage for conducting liquid sample to said separating chamber from said fluid feed chamber.

7. Centrifuge apparatus as defined in claim 6 wherein said center post is removable from said bowl.

8. Centrifuge apparatus as defined in claim 5 wherein said bowl includes a cylindrical opening at one end, the wall of said opening merging with the inner wall of said bowl, and wherein said releasable means includes a center post disposed coaxially of said bowl and extending into said opening to form a fluid passage leading out of said separating chamber, said passage being defined between the exterior of said center post and said wall of said cylindrical opening, said center post being hollow to form a fluid feed chamber and open at one end to receive liquid sample, and a fluid passage interconnecting said fluid feed chamber and said separating chamber.

9. In centrifuge apparatus, a rotor assembly for centrifugation of liquid sample and resuspension of sediment recovered therefrom, said rotor assembly comprising a hollow bowl formed with an upwardly extending inner wall, core means having an outer surface and being contractable under radially inwardly-acting centripetal forces generated during centrifugation thereby forming a separation chamber, said separation chamber being defined between said inner wall of said bowl and said outer surface of said core means, and said core means expanding to ride along said inner wall of said bowl in scraping contact to scrape said sediment therefrom when said centripetal forces decrease after centrifugation.

10. Centrifuge apparatus as defined in claim 9 further including fluid passage means for conducting liquid sample continuously into and out of said separation chamber during centrifugation.

11. A centrifuge rotor assembly for centrifugation of liquid samples and resuspension of sediment recovered therefrom comprising a hollow bowl formed with an upwardly extending inner wall, a core assembly including a core body carried within said bowl and mounted to be rotated therewith about a vertical axis for centrifugation operation, said core body formed from a plurality of discrete, loose segments carried within said bowl and having a substantially cylindrical outer surface, said core body being subject to centrifugal forces generated during centrifugation and acting radially inwardly to contract said outer surface of said core body to provide a separation chamber for accumulating said sediment, said chamber being defined by said inner wall of said bowl and said outer surface of said core body, and said core body being free upon withdrawal of said forces to move into contact with said inner wall of said bowl for resuspending said sediment, whereby during centrifugation said segments move away from said wall and during resuspension operations said segments move into contact with said wall.

12. Centrifuge apparatus as defined in claim 11 wherein said core body segments are movable radially to and from said inner wall of said bowl, said segments having a predetermined specific gravity.

13. Centrifuge apparatus as defined in claim 11 wherein said core body is separated into a plurality of segments arranged in tiers stacked to rest loosely one upon the other.

14. Centrifuge apparatus as defined in claim 11 wherein said core body has a transverse cross section defining an annulus separated into a plurality of segments, each segment forming a generally pie-shaped portion of the annulus.

15. A centrifuge apparatus as defined in claim 11 wherein said core body is separated into a plurality of segments arranged in tiers stacked to rest loosely one upon the other, said core body having a transverse cross-section defining an annulus, each segment forming a generally pie-shaped portion of said annulus.

16. Centrifuge apparatus as defined in claim 11 wherein said segments are provided with scraping elements disposed to coact with said inner wall of said bowl.

17. Centrifuge apparatus as defined in claim 12 wherein the specific gravity of said segments is less than said liquid sample.

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