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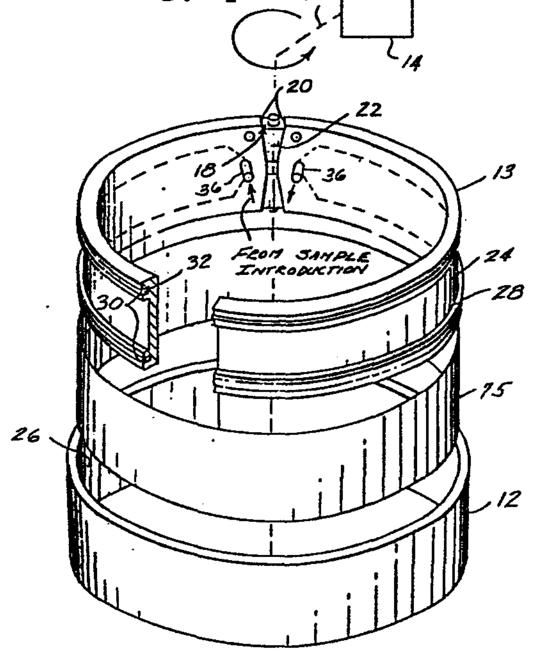
(54) **Film insert for sedimentation field flow fractionation channel.**

(57) A replaceable thin film is disposed against the outer wall of a sedimentation field flow fractionation channel.

FIG. 1



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TITLE

FILM INSERT FOR SEDIMENTATION FIELD FLOW FRACTIONATION CHANNEL

BACKGROUND OF THE INVENTION

Field flow fractionation is a versatile technique for the high resolution separation of a wide variety of particulates suspended in a fluid medium. The particulates include macromolecules in the 10^5 to the 10^{13} molecular weight (0.001 to 1 µm) range, colloids, particles, micelles, organelles and the like. The technique is more explicitly described in U.S. Patent No. 3,449,938, issued June 17, 1969 to John C. Giddings and U.S. Patent No. 3,523,610, issued August 11, 1970 to Edward M. Purcell and Howard C. Berg.

In the case of sedimentation field flow fractionation (SFFF), use is made of a centrifuge to establish a force field for separating the particulates. For this purpose a long, thin annular belt-like channel is made to rotate about its axis in a centrifuge. The resultant centrifugal force causes components of higher density than the mobile phase flowing in the channel to sediment toward the outer wall of the channel. For equal particulate density, because of higher diffusion rates, smaller particulates will accumulate in a thicker layer against the outer wall than will larger particulates. On the average, therefore, larger particulates are forced closer to the outer wall.

If now the mobile phase or solvent is fed continuously from one end of the channel, it carries the sample components through the channel for later detection at the outlet of the channel. Because of the shape of the laminar velocity profile of the solvent within the channel and the placement of

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particulates in that profile, solvent flow causes smaller particulates to elute first, followed by a continuous elution of components in the order of ascending particulate mass.

In order to reduce the separation times required using this technique, it is necessary to make the channels relatively thin. This creates many problems in that the walls of the channel must have a microscopically smooth finish to prevent the particulates from sticking to the walls or being trapped in crevices of the same height as the particulate distributed. Unfortunately, in the construction of such a thin belt-like channel for use in a centrifuge, the microfinish cannot be easily obtained or maintained. Another problem is that, even though the walls of the channel have a microfinish, the particulates in many instances tend to adhere to the walls of the channel. This problem is noted by Purcell et al. at column 4, line 43 who suggest it is necessary to select for the surface of the channel wall a material to which the particle will not be adsorbed.

It would be desirable to obtain a channel whose outer wall has a removeable or replaceable surface that can be changed for cleaning or according to the particulates being separated to reduce adhesion of the particulates to the walls. Furthermore, it would be desirable to provide a channel in which the walls need not be finished to such microscopic surface in the first instance thereby resulting in lower cost channels.

To facilitate cleaning, the channels are usually formed of two mating rings. This creates a problem in that leaks can occur at the interface between the rings.

SUMMARY OF THE INVENTION

According to one aspect of this invention, an apparatus is constructed for separating particulates suspended in a fluid medium according to their effective masses. This apparatus includes an annular, cylindrical channel having a cylinder axis, means for rotating the channel about the axis, means for passing the fluid medium circumferentially through the channel, and means for introducing the particulates into the medium for passage through the channel. The channel is defined by an outer support ring having a constant inner radius, and a unitary inner ring mating with the outer ring to define the channel therebetween.

This channel is improved according to this invention by constructing the channel to have a replaceable, thin film disposed between the rings and in contact with the outer ring forming the outer channel wall. This greatly facilitates cleaning of the channel. With this construction, the outer support ring need not have a microfinish; rather it can rely simply upon the film to provide such finish. The film is particularly useful in that it aids in sealing the channel to prevent leakage at the interface between the rings.

The particular film may be selected according to the particulates to be separated, the objective being to prevent the particles from adhering to the film surface of the outer wall. The outer ring or wall may be formed either by a separate ring or by the inner wall of a conventional zonal rotor centrifuge. The inner ring may be continuous or split. The film may be coated with a material or its surface may be modified using known techniques to reduce adhesion of the particulates to the outer support ring. Typically, the film may be a polymeric material that is flat, smooth, of a desired surface chemically to reduce particulate adhesion, resilient, insoluble in the solvents normally used, and noncorroding.

BRIEF DESCRIPTION OF THE DRAWINGS

Further advantages and features of this invention will become apparent upon the following description wherein:

FIG. 1 is an exploded pictorial representation of mating split rings that may be used to form a sedimentation field flow fractionation channel utilizing a film interfaced between the rings;

FIG. 2 is a fragmentary cross sectional view of a channel formed in accordance with this invention utilizing the film insert wherein the outer ring constitutes the inner wall of a zonal rotor centrifuge;

FIG. 3 is a cross-sectional elevation view of a continuous ring channel, utilizing the film insert of this invention, constructed to be submerged in a fluid.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Typical sedimentation field flow fractionation apparatus with which this invention may find use are described in U.S. Patent 4,283,276 issued August 11, 1981 to John Wallace Grant, U.S. Patent 4,353,795 schedule to issue October 12, 1982, copending application Serial No. 326,156, filed November 30, 1981 and entitled "Apparatus and Method for Sedimentation Field Flow Fractionation" by Dilks et al. (IP-0304) and copending application Serial No. 326,157, filed November 30, 1981 and entitled "Sedimentation Field Flow Fractionation Channel and Method" by Dilks et al. (IP-0313).

As is described in the Grant patent, split ring, SFFF channels 10 (FIG. 2) are constructed to have an outer ring 12, which is in the form of a band having a constant inner radius and functions to support an inner ring 13. Actually, the outer ring 12 may be supported by a spider, bowl, or disc which is driven directly by a rotor 14 acting through a linkage depicted by the dashed line 16. The Romanauskus patent describes one such mounting in which the outer ring is supported by compression washers which follow the expansion of the ring during centrifugation. Alternatively, the outer ring may be eliminated and a bowl type rotor substituted. In this event, the bowl rotor has a cylindrical inner surface formed thereon to provide the outer channel wall.

The inner ring 13 is split, i.e., its longitudinal circumference is divided or separated to have a gap 18 with the longitudinal ends 20 of the inner ring 13 slightly tapered to facilitate the use of wedges 22. The wedges 22 retain the inner ring sufficiently expanded to maintain contact with the outer ring 12 at all times even when stopped. The radially outer wall 24 of the inner ring 12 and the radially inner wall 26 of the outer ring 56 are formed to define the channel 10. Normally these walls are formed as by polishing, for example, or by coating the surfaces with a suitable material to have a microfinish. This smooth finish tends to reduce the possibility that particles will stick to the walls or become entrapped in small crevices or depressions and also insures that the expected sample retention takes place.

Depending upon the needs of the operation, a groove 28 may be formed in the outer wall 24 of the inner ring 13 form the flow channel 10. Along the edges of the channel groove 28, subsidiary grooves 30 may be formed to accommodate a resilient seal 32, such as an O-ring, which completely surrounds and tracks along the edges of the channel, including the end sections. Additionally, the upper edge of the inner ring is formed with a radial, outwardly extending flange 34, as is seen most clearly in FIG. 2, such that the inner ring may rest upon and be supported by the outer ring against axially downward displacement. Inlet and outlet conduits 36 communicate with the ends of the channel 10 through the inner ring. As is known, fluids containing particulate samples are passed through these conduits. The outlet conduit is coupled to a detector (not shown). As noted, the thickness of this channel 10 is relatively small, typically being in the order of 0.1 cm or less. The dimensions of the channel, both width and thickness must be very precisely maintained. The actual thickness is selected according to the separations to be performed as is known.

In accordance with this invention, a thin, flat film 75 of a resilient, smooth surfaced material is positioned in between the inner and outer rings 13, 12. This film typically is placed over the inner ring, the ring compressed (the wedges 22 being removed) and placed within the outer ring (which of course may be the inside wall of a bowl rotor) and the inner ring allowed to release to expand and force the film in contact with the outer wall. The wedges are then reinserted to stabilize the inner ring as described by Grant. This film, which may be of any polymeric material or even aluminum or stainless steel, provides the smooth surface for the outer wall without the need for the normal polishing that would normally be required. The film extends beyond the O-ring seals to aid in sealing to prevent leakage of fluids from the channel. In fact, in many cases the seals may be omitted when a resilient film insert is used.

The films that may be used should be flat, have a smooth surface and the desired surface chemical characteristics, be resilient, insoluble in the mobile phase used, noncorroding, and desirably colored for ease of handling. Among the films that may be used are cellulose, polyethylene terephthalate, polytetrafluoroethylene, aromatic polyimide, polypropylene, polyvinyl acetates, and polyvinyl propionate polyesters. These tend to provide hydrophobic surfaces. If hydrophilic surfaces are desired, the above noted materials in many cases can be treated or coated. Film thickness typically should exceed 0.005 cm. Thinner films than this have a tendency to wrinkle, which is highly undesirable for this purpose. Films up to .02 cm thickness have been used successfully. Films significantly in excess of this thickness may be used but tend to be unnecessarily wasteful of the film material. Films having a thickness in the range of .01 cm are particularly desirable. They do not change the dimension of the channel's thickness, unless the channel is formed by a groove in the outer ring, since they simply serve to coat the inner wall of the outer ring. Metal films that may be used include aluminum and stainless steel which may be gold plated if desired.

In SFFF separations, samples of particulates in suspension are introduced into a mobile phase which carries the particulates through the channel

10. The particulate under test will determine the mobile phase and the type of film 75 that is used. Adhesion between the channel outer wall and the particulates is to be avoided--it reduces the resolution and sensitivity of the separation.

In accordance with this invention, such adhesion can be avoided by properly selecting or coating or modifying the surface of a film. Adhesion usually occurs where the surface charge of the particulate and the film's surface polarity are opposite. It also occurs where there is covalent bonding, chemical adsorption, or van der Waals forces. Ideally the channel should "look like" the mobile phase, i.e., be of the same polarity.

It also is important that the mobile phase density be less than the particulate density and that the mobile phase wets the particulates. If the particulates are hydrophobic, the mobile phase should be nonaqueous. If the particulates are hydrophilic, the mobile phase should be aqueous. Although of secondary importance, it is desirable that the mobile phase wets the channel walls.

In the event a hydrophilic surface is desired, many of the above noted polymeric films which are hydrophobic, may be surface modified. This typically is accomplished by forming OH or carboxyl groups on the surface as by chemically bonding desired molecules to reactive sites on the surface. Alternatively the hydrocarbons may be oxidized by a corona discharge, the fluorocarbons may be reduced by sodium in ammonia, esters, amides and imides may be hydrolyzed. Cellulose and polyvinyl alcohol have hydrophilic surfaces.

The replaceable film of this invention finds use with any double ring or other type SFFF channel which can be opened for cleaning and the like. For example, it may be used in the "floating" type channels described in the copending Dilks and Yau and Dilks, Yau and Kirkland applications mentioned above. These channels are formed with a continuous inner ring as is the Romanauskus channel. Dilks and Yau describe a disklike channel 10 as seen in FIG. 3. This channel 10 is formed by an inner ring or hub 76 and a mating outer ring 80 positioned in the bowl of a rotor 60. The hub 76 and outer ring 80 are formed to have a diametrical interference fit of about 0.03 centimeters (cm) so that the outer ring 80 is in constant compressive contact with the hub 76 under static conditions. The inner or mating surface 82 of the outer ring 80 has a channel or groove 84 formed therein leaving lands 81 on either side of the groove 84. The outside portions 85 of the inner surface 82 are removed to limit the axial width of the lands 81 and thereby enhance their ability to seal the channel when they contact the peripheral surface of the hub 76. This groove 84 may be formed to have different thicknesses, different widths, different lengths, different aspect ratios (width to thickness ratio).

In accordance with this invention, a strip of film 75, as described, is positioned against the inner wall of the outer ring 80. This is accomplished by cooling the inner ring, wrapping the film about the inner ring, inserting the inner ring 76 into the outer ring 80 while the film is maintained under tension, and allowing the inner ring to expand. Air may be removed from the inner wall of the outer ring by forming it with a matte finish. When liquid is later introduced into the channel 10, it will expand the film into the groove 84 to define the channel.

The beginning and end of each channel and the manner in which fluids are fed to and withdrawn therefrom are preferably those described in U.S. Patent 4,284,498 issued to Grant et al. on August 18, 1981, the disclosures of which is incorporated herein by reference. Fluids are fed through tubing 74 to circumferentially spaced radial bores 83 in the hub 76 to the beginning and end of the channel 10. The beginning and end of the channel groove 84 is defined by a plastic shim (not shown) having a close fit with the channel axial width. The shim has inverted V-shaped ends with the apex of the V slotted to encompass the respective bores 83. The shim may be formed of a polyphenylene oxide plastic and be cemented into position. It may be slightly thicker than the depth of the channel groove 84. Thus, when it is compressed by the smooth outer peripheral surface of the hub 76, it seals and defines the beginning and end of the channel 10.

The interior of the bowl-type rotor 60 preferably is filled with a liquid of approximately the same density as the fluid medium that is forced to flow through the channel. Further, the outer ring 80 is formed to have a diameter slightly less than the interior diameter of the bowl 60 so that it does not contact the inside of the bowl even during centrifugation. On the other hand, the hub 76 is configured so that it fits concentrically over the interior hub 94 of the rotor 60, so as to be mounted securely thereon, and to have a nib 96 that engages a receptacle 98 in the cover 70 to center the channel housing 76, 80. The mid-portion 100 of the hub 76 may be in the form of an annulus having a reduced thickness to facilitate the radially outward expansion of the hub 76 during centrifugation to facilitate its following the outer ring expansion.

Liquid, typically water or other aqueous based liquid, thus surrounds essentially all of the channel housing 76, 80. Under these conditions, when the rotor 60 is rotated, centrifugal force causes the liquid pressure exerted by the liquid in the rotor bowl 60, external to the channel, and that exerted internally by the fluid medium within the channel to be substantially equal. Since, leakage is essentially eliminated at the interface 81 between the hub and outer ring the width of the film may be selected to match the axial width of the groove 84. In this manner it finds use in reducing particulate adherence to the outer channel wall and the ability to remove and replace films according to the particulates to be separated.

As described by Dilks et al., the hub 76 and outer ring 80 preferably are each constructed of a suitable engineering plastic selected such that the effective density ϕ to tensile modulus E ratio of the outer ring is somewhat less than the effective density ϕ to tensile modulus E ratio of the hub. The effective density ϕ is the density of the channel material minus the density of the bowl filling liquid. The effective density ϕ of course can be negative. This is done so that the hub can expand outwardly to a greater extent than the outer ring to maintain a good contact, during centrifugation, with the outer ring and thereby maintain the integrity of the channel. In addition, if the density of the outer ring is less than that of the hub, the density of the compensating liquid can be selected to be different from the density of the fluid medium and to lie between the densities of the hub and outer ring. When the compensating liquid density exceeds that of the outer ring, the outer ring will literally float under a force field and be forced to have closer contract with the inner ring.

If the density of the outer ring is greater than that of the inner ring, then the use is limited to compensation liquid densities less than that of the hub or else the hub can separate from the outer ring under some operating conditions. With the effective density ϕ to tensile modulus E ratio of the outer ring less than the effective density ϕ to tensile modulus E ratio of the hub, the hub will expand under centrifugal force at a faster rate than the outer ring and maintain good contact therebetween during centrifugal operation. Preferably, the density of the compensating liquid within the rotor is selected to be approximately equal to the density of the outer ring such that there is little expansion or contraction of the outer ring due to the effects of the liquid.

There has thus been described a relatively simple mechanism for reducing the expense of preparing SFFF channels. The films may be used typically to coat the inner wall of the outer ring of any particular channel whether the outer wall be formed by a zonal rotor, an outer ring or whatever.

The advantage accruing from the use of this film are many. The finish of the outer channel wall need not require costly machining operations to obtain as microfinish--it is provided by the smooth surface of the film. The film is easily replaceable for cleaning the channel, to provide surface characteristics matching those of the particulates, and to reduce channel leakage.

CLAIMS

1. In an apparatus for separating particulates suspended in a fluid medium according to their effective masses, said apparatus having an annular cylindrical channel with a cylinder axis, means for rotating said channel about said axis, and means for passing said fluid medium circumferentially through said channel, the channel having an outer support ring with a constant inner radius, and unitary inner ring mating with the outer ring to define the channel therebetween, the improvement wherein:

a replaceable thin film is disposed between said rings and in contact with the outer ring, thereby to provide a replaceable outer wall for said channel.

2. The apparatus of claim 1 wherein said inner ring has an outer wall the middle portion of which defines a circumferential groove of constant depth to form the channel.

3. The apparatus of claim 1 wherein said inner ring is separated at one point along its circumference and the channel begins and ends on either side of the separation.

4. The apparatus of claim 1, 2 or 3 wherein the film is a resilient, smooth material.

5. The apparatus of claim 1, 2 or 3 wherein the film is coated with a material that reduces adhesion of the particulates to the outer support ring.

6. The apparatus of claim 1, 2 or 3 wherein said film has a surface modified chemically to reduce the adhesion of the particulates to the outer support ring.

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7. The apparatus of claims 1, 2 or 3 wherein the film is a polymeric material selected from the group consisting of polyester, polypropylene, polyethylene, polyvinylacetate, polyvinyl propionate, polyoxymethylene, polyethylene terephthalate, tetrafluoroethylene, and aromatic polyimide.

8. The apparatus of claim 1 wherein the film is a resilient, smooth, polymeric material, thereby to reduce leakage from the channel through the interstitial space between the rings.

9. The apparatus of claim 8 wherein the surface of the film is modified to be hydrophilic.

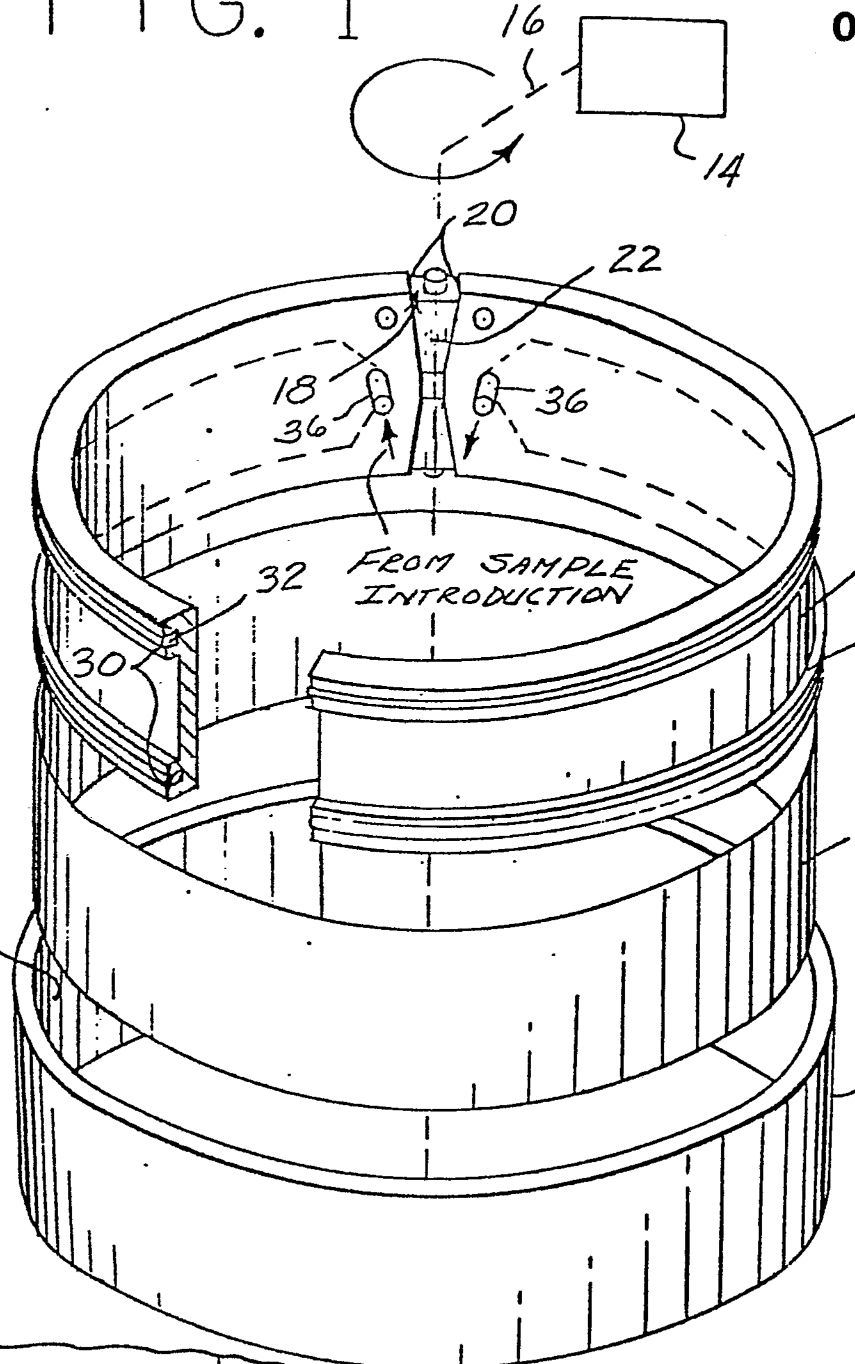
10. In a channel for separating particulates by sedimentation field flow fractionation comprising an outer support ring with a constant inner radius, a unitary inner ring mating with the outer ring to define the channel therebetween, the improvement wherein

a replaceable thin film is disposed between said rings and in contact with the outer ring, thereby to provide a replaceable outer wall for said channel.

11. The channel of claim 10 wherein the film is a resilient, smooth, polymeric material, thereby to reduce leakage from the channel through the interstitial space between the rings.

12. The channel of claims 10 or 11 wherein said film has a surface modified chemically to reduce the adhesion of the particulates to the outer support ring.

FIG. 1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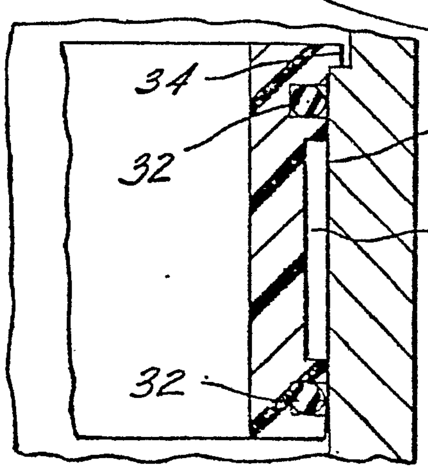
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FIG. 2

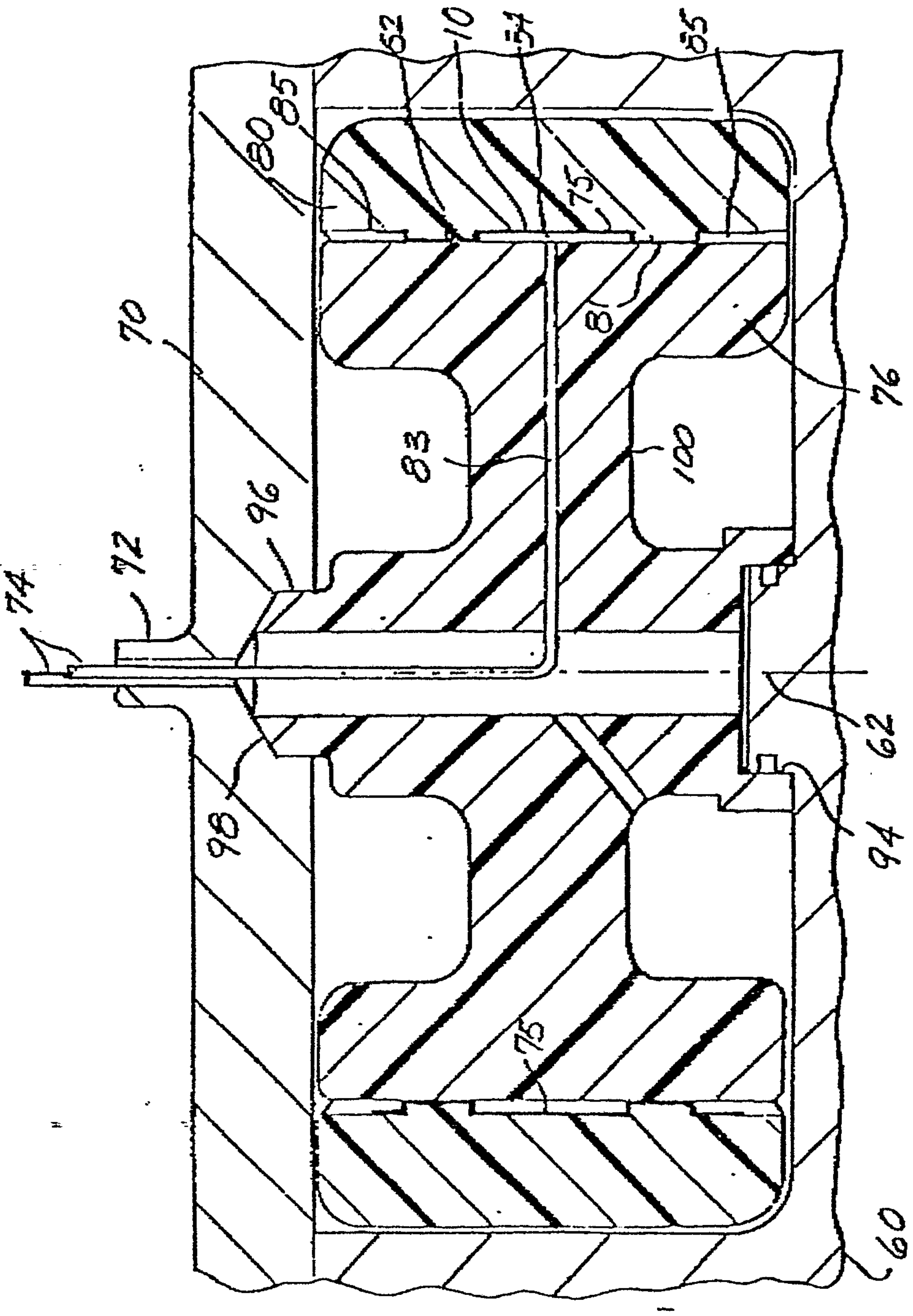

FIG. 3