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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
11 November 2010 (11.11.2010)

PCT

(10) International Publication Number
WO 2010/127686 A2

(51) International Patent Classification: Not classified

(21) International Application Number: PCT/EP2009/003273

(22) International Filing Date: 7 May 2009 (07.05.2009)

(25) Filing Language: English

(26) Publication Language: English

(71) Applicant *(for all designated States except US)*: **MAX-PLANCK-GESELLSCHAFT ZUR FÖRDERUNG DER WISSENSCHAFTEN E.V.** [DE/DE].

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **KHALILI, Arzhang** [DE/DE]; Weissdornpfad 48a, 28355 Bremen (DE). **JAVADI, Khodayar** [IR/DE]; Voltastrasse 51, 28357 Bremen (DE). **MEYER, Volker** [DE/DE]; Am Hochzeitswald 21a, 27711 Osterholz-Scharmbeck (DE).

(74) Agent: **V. BEZOLD & PARTNER**; Akademiestrasse 7, 80799 München (DE).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

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

Published:

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

(54) Title: METHOD AND DEVICE FOR SHEAR STRESS GENERATION AND FLOW CONTROL

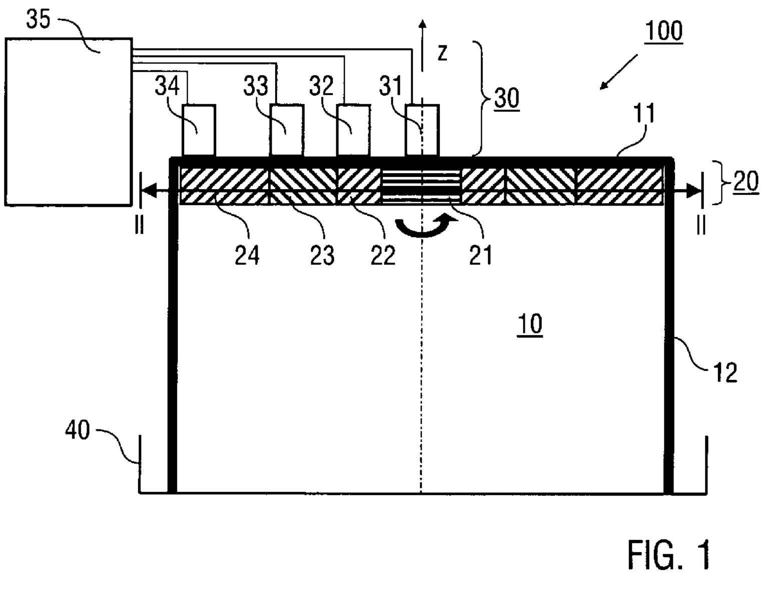


FIG. 1

(57) Abstract: A method of generating a circular motion of a liquid in a chamber (10), in particular for generating bottom shear stress and flow control in a chamber (10), comprises the steps of providing a spinning device (20) rotating around a central axis (z) in the chamber (10), and subjecting the liquid to a driving force provided by the spinning device (20), so that a liquid column rotating around the central axis (z) is created, wherein the spinning device (20) comprises at least two rotating components (21, 22, 23, 24, 25, 26, 27) concentrically arranged in contact with the liquid, and the rotating components (21, 22, 23, 24, 25, 26, 27) being rotated with different angular velocities. Furthermore, a reaction device (100) is described, which in particular is adapted for subjecting a sample in a liquid to a predetermined shear stress.

WO 2010/127686 A2

Method and device for shear stress generation and flow control

Subject of the invention

The invention relates to a method of generating bottom shear stress and flow control in a chamber, in particular to a method for creating a homogeneous, controllable uniform shear stress applied to a sample in the chamber. Furthermore, the invention relates to a reaction chamber being adapted for conducting the above method, in particular to a reaction chamber being adapted for creating a homogeneous, controllable shear stress on a sample. Applications of the invention are available e.g. in process engineering, medicine, biotechnology and marine sciences.

Technical background

Generating planes with uniform shear stress is required for investigating sample-liquid-interactions or samples under certain liquid flow conditions, like e.g. in studying growth of cultures in bioreactors or in investigating cell death characterized by DNA fragmentation in the human body. Reactor devices generating planes with uniform shears stress are also frequently used in the context of marine sciences as described in following.

The sea floor plays an important role in the regulation of the chemical composition of water masses in oceans. Biogeochemical processes, chemical reactions and flux exchanges appear in a very thin near-bed layer at a sediment-water-interface. Reactor devices are used for studying sediment dynamics by in-situ measurements. For this application, a reactor device comprises a semi-enclosed chamber, which is pushed partially to the sediment and which is equipped with a water mixing device. For simulating real hydrodynamic conditions, the water mixing device (or: spinning device) typically is adapted for creating a rotating liquid column in the chamber.

A rotating liquid column, which is driven e.g. by a rotating platform in the chamber, is inherently characterized by an angular velocity profile. In the centre and at the outermost boundary of the liquid column, the angular velocity is zero, while an angular velocity maximum is obtained at any position between the centre and the outermost boundary. Creating a rotating liquid column with a velocity profile represents a restriction for investigations of the sediment-water-interface as a non-uniform shear stress distribution is created. Various conventional approaches for providing a uniform shear stress distribution are known.

As a first example, US 4 973 165 discloses a reaction device 100′, which is schematically illustrated in Figure 7A (prior art). The conventional reaction device 100′ comprises a chamber 10′ and a spinning device 20′, which is adapted to create a rotating liquid column in the chamber. The chamber 10′ comprises an inflow opening 11′ and a discharge opening 12′. The spinning device 20′ comprises a rotating platform 21′ with a hollow axis representing the discharge opening 12′. As a modification, the platform 21′ can be provided with a circumferential skirt, which is aligned in parallel to a sidewall of the chamber 10′. The conventional reaction device 100′ is provided for rotating the spinning device 20′ while simultaneously supplying a liquid volume through the inflow opening 11′ and removing a liquid volume through the discharge opening 12′.

An analysis of the hydrodynamics in the conventional reaction device 100′ (see A. Khalili et al. in "Recent patents on chemical engineering" Vol. 1(3), 2008, p. 174-191) shows that even with the inflow-discharge technique illustrated in Figure 7A, an inhomogeneous shear stress distribution is created. As an example, Figure 7B shows bottom shear stress in a marine science application as a function of radius (see Figure 8 of the above publication of A. Khalili et al.). System I mentioned in the figure denotes a disk-cylinder system without suction-injection device, whereas systems II and III denote the device 100' (of Figure 7A) without and with a circumferential skirt, resp.. This result shows that the conventional reactor device 100' creates an essentially inhomogeneous shear stress distribution above the bottom of the chamber 10'.

The above requirement of generating a homogeneous shear stress distribution with a rotating liquid column is relevant not only in the above marine applications but also in incubation studies of sample-liquid-interfaces, like e.g. investigations of a distribution of nutrients in biological reactors, flux exchanges or ongoing chemical reactions. Further tasks in biology and cell culturing can be related to animal cells, fragmentation of DNA or handling proteins.

For example, devices which could be used for generation of shear stress in cell culturing technology are disclosed in the patents US 6 193 883 B1, US 2005/0032200 A1 and US 2008/0038816 A1. With these devices, the rotating platform shown in Figure 7A is replaced by a rotating cone 22' (Figure 8A, prior art). The tip of the cone 22' has a distance h from the bottom of the chamber (radius R). Due to the cone shape, a velocity distribution is induced in the rotating liquid column. However, as shown in an investigation by K. Javadi and A. Khalili in "Recent patents on chemical engineering" (unpublished on the priority date of the present specification), in general, these devices do not yield a homogeneous shear stress at the chamber bottom. As an example, Figure 8B shows bottom shear stress in a cell culturing technology application for a linear or curved cone shape with the distance h [µm] as a parameter.

Objective of the invention

The objective of the invention is to provide an improved method of flow control by generating a desired circular motion of a liquid in a chamber, which is capable of avoiding disadvantages and restrictions of conventional techniques. In particular, it is the objective of the invention to create a rotating liquid column having a homogeneous distribution of angular velocity and generating a uniform bottom shear stress. Furthermore, it is a partial aspect of the objective of the invention to facilitate an adaptation of the above method to different operation conditions, e.g. to different liquids, velocities and/or reactors sizes. Furthermore, the objective of the invention is to provide an improved reaction device, which in particular is adapted for subjecting a sample in a liquid to shear stress, which reaction device is capable of avoiding disadvantages and restrictions of conventional techniques.

Summary of the invention

The above objectives are solved with a method and/or a reaction device comprising the features of the independent claims, respectively. Preferred embodiments of the invention are defined in the dependent claims.

According to a first aspect of the invention, a method of generating a circular motion of a liquid in a chamber is provided, wherein a spinning device is operated to rotate around an axis in the chamber and a rotating liquid column is created by a driving force applied by the spinning device to the liquid. According to a second aspect of the invention, a reaction device, being in particular adapted for subjecting a sample in a liquid to a shear stress, is provided, which comprises a chamber accommodating the liquid and a spinning device rotating around an axis in the chamber. According to the invention, the spinning device comprises at least two rotating components concentrically arranged in contact with the liquid, wherein the rotating components are rotated with different angular velocities. To this end, the reaction device has a driving device being adapted to drive the rotating components with the different angular velocities.

The rotating components form a driving surface which contacts the liquid to be moved. The capability of the rotating components to be controlled individually has the advantage that different driving forces - which depend on a radial distance from the axis of rotation - can be applied to the liquid. Thus, a radial velocity distribution can be adjusted wherein effects of external friction relative to a circumferential outer boundary of the liquid column and internal friction in the liquid can be compensated.

Depending on the application of the invention and the number of rotating components, any radial velocity profile can be created in the liquid column. However, according to a preferred embodiment of the invention (generating a uniform shear stress), the rotating components are controlled such that the angular velocity of a rotating component with a first diameter is larger than the angular velocity of a second rotating component of a second larger diameter. Similarly, the second rotating component has a larger angular velocity compared to a third one, and so forth. In other words, for this application the velocities are decreasing with increasing radii of the rotating components. The liquid velocity is adjusted to be free of radial gradients. Thus, a homogeneous shear stress distribution can be created with the liquid column, in particular on a bottom of the chamber.

According to a further advantage of the invention, various techniques are available for driving the rotating components. According to a first variant, at least one electric motor is utilized for subjecting the rotating components to predetermined rotation frequencies. The electric drive has advantages in terms of the quantitative forces exerted to the liquid. According to a second variant, at least one magnetic drive is utilized for driving the rotating components. As an advantage, moving parts are avoided in the driving device. According to a third variant, both electric and magnetic drives can be used in combination.

According to a further preferred embodiment of the invention, the reaction device is operated as a closed system. At least during the creation of the rotating liquid column, the chamber is closed relative to a surrounding area or a fluidic system possibly connected with the chamber. With this embodiment, any supply inflow or discharge outflow of liquid is suppressed. The provision of the closed system represents an essential advantage compared with the above conventional technique (US 4 973 165), in particular in terms of reproducible chemical conditions in the chamber and reduced liquid consumption.

Alternatively, according to another modification of the invention, the chamber can be provided with at least one inflow and/or outflow opening if required in a specific application of the invention.

According to a further preferred embodiment of the invention, the rotating components comprise a central platform and at least one circular ring (ring disk), preferably at least two circular rings, particularly preferred at least three circular rings concentrically arranged around the central platform. The central platform has a circular closed surface, the centre of which being intersected of the liquid column axis. Alternatively, the central platform has a central hole, i.e. the central platform has also a ring shape. With this embodiment, the rotating components comprise at least two circular rings, preferably at least three circular rings, particularly preferred at least four circular rings concentrically arranged relative to each other.

According to a modification of the invention, a rotating perimeter sleeve can be provided, which is arranged for azimuthally enclosing the liquid column. Advantageously, the outer boundary of the liquid column is driven by the perimeter sleeve, so that a drop of the tangential components of the liquid velocity can be avoided. Preferably, the rotating perimeter sleeve is connected, in Particular integrally formed with the outermost ring of the rotating components.

The rotating components can provide a plane boundary relative to the liquid in the chamber. In this case, the rotating components have a flat shape. According to a further modification of the invention, the flat rotating elements can be replaced by rotating elements having tilted surfaces. In particular, the rotating elements can be shaped such all rotating components together form a cone shape.

According to a further preferred feature of the invention, the chamber at least partially is made of an optically transparent material. Advantageously, an optical beam path, e. g. a detection path and/or an illumination path can be directed through a chamber wall for optical investigations of a sample in the chamber.

According to yet a further preferred feature of the invention, the chamber at least partially is made with a polished inner surface. Thus, wall roughness effects can be minimized.

As a further advantage, the invention has multiple applications in various field of biology, chemistry, ecology, process engineering, bioengineering as well as crystal growth. In particular, with the rotating liquid column a shear stress can be created on a sample, which comprises a sediment surface, a cell culture or a solid phase reaction component, like e.g. a porous substrate, or with the other application of generating planes with uniform shear stress noted above.

Brief description of the drawings

Further details and advantages of the invention are described in the following with reference to the attached drawings, which show in:

Figure 1: a cross-sectional view of a first embodiment of the inventive reaction device,

Figure 2: a sectional view of the embodiment of Figure 1 taken along line II-II;

Figure 3: a cross-sectional view of a second embodiment of the inventive reaction device;

Figure 4: a cross-sectional view of a third embodiment of the inventive reaction device;

Figures 5 and 6: graphical representations of shear stress distributions obtained with the inventive technique; and

Figures 7 and 8: illustrations of conventional techniques (prior art).

Preferred embodiments of the invention

Preferred embodiments of the invention are described in the following with exemplary reference to reaction devices (or: so-called microcosm chambers) applied in marine applications. It is emphasized that the application of the invention is not restricted to marine sciences, but rather possible with other tasks of hydrodynamic investigations. Furthermore, exemplary reference is made to a reaction device, which is utilized in a laboratory or a chemical processing apparatus, wherein a bottom opening of the chamber of a reaction device is closed by a sample carrier. The invention can be correspondently applied without the sample carrier by *in situ*-investigations, wherein the sample is directly set on or partially into a sample surface.

Figures 1 and 2 schematically illustrate a first embodiment of the reaction device 100 of the invention, wherein Figure 1 illustrates a sectional view along an axial direction (corresponding to line I - I in Figure 2) and Figure 2 illustrates a sectional view along a radial direction (corresponding to line II - II in Figure 1). The reaction device 100 comprises a chamber 10, a spinning device 20, a driving device 30 and a sample carrier 40. The chamber 10 has a cylindrical shape with a cylinder axis (z-axis) being aligned perpendicular to a plane surface of a sample carrier 40.

The chamber 10 comprises a cover wall 11 extending perpendicular to the z-axis and a circumferential side wall 12. The cover wall 11 is an upper closure of the chamber 10 in axial direction and simultaneously a holder of the spinning device 20. Depending of the structure of the spinning device 20 and the type of the driving device, the cover wall 11 has bearings for the rotating components of the spinning device 20 on its inner surface. The bearings comprise e.g. sleeve bearings each being adapted for accommodating one of the rotating components of the spinning device 20 (see below).

The chamber 10 is made of solid material, e.g. metal sheet, ceramic, glass and/or plastic material. The cover and side walls 11, 12 can be integrally made of one single material, like e.g. plastic material. Alternatively, the cover wall 11 and the side wall 12 can be made of different materials. Preferably at least a portion of the side wall 12 is made of an optically transparent material, like e.g. transparent plastic material, e.g. PMMA. In this case, optical measurements with an optical monitoring device, like e.g. a camera (not shown) arranged outside the chamber 10 are facilitated.

Depending on the particular application, the chamber 10 and the sample carrier 40 can be adapted for a fixed sealed connection, e. g. using a clamping mechanism and a sealing ring (not shown). Alternatively, the chamber 10 can be simply set onto the sample carrier 40 and a sealing can be omitted, if the reaction device 100 is accommodated in a container including the liquid or if it is used for *in situ*-investigations.

The combination of the chamber 10 and the sample carrier 40 provides a closed system. The cover and side walls 11, 12 are closed walls. Typically, they are provided without any supply or discharge openings. Alternatively, at least one of them is provided with at least one liquid access opening, which can be open for supply or discharge before a reaction or investigation, and otherwise closed, in particular during the operation of the reaction device.

The spinning device 20 comprises multiple rotating components, which are concentrically arranged relative to z-axis and which can be separately driven with the driving device 30. These rotating components comprise a central rotating platform 21 and at least one circular ring 22. In the illustrated embodiment, three concentric rings 22, 23 and 24 are illustrated. Depending on the application of the invention, a larger or a lower number of rings can be provided. Furthermore, with a modified embodiment of the invention, the central rotating platform 21 can be omitted or replaced by another ring (see Figure 3). The rotating components 21 to 24 can be made of e. g. plastic material, like PMMA, or metal. The lower surfaces of the rotating components 21 to 24 can be provided with a roughening adapted for increasing the friction with the liquid in the chamber 10.

The rotating components 21 to 24 of the spinning device 20 can be provided with a form-locking arrangement. In this case, the outer diameter of an inner rotating component, e.g. ring 22, equals the inner diameter of the adjacent outer rotating component, e.g. ring 23. Alternatively, angular gaps may be provided between the rotating components 21 to 24 (not shown). The platform 21 and the rings 22 to 24 extend in a plane perpendicular to the z-axis. They are arranged such that the lower surfaces thereof provide a flushing surface facing to the inner space of chamber 10, which flushing surface eventually may be interrupted by the annular gaps between the rotating components 21 to 24.

On the upper side of the rotating components 21 to 24, projections are provided, which are accommodated in the sleeve bearings of the cover wall 11. Additionally, each of the rotating components 21 to 24 is provided with an engagement structure like e.g. a tooth rim. Each engagement structure is in engagement with a drive shaft of an electric motor of the driving device 30.

The driving device 30 comprises electric motors 31 to 34 each being arranged for driving one of the rotating components 21 to 24 of the spinning device 20, respectively. The electric motors are connected with a power supply and control unit 35, which is adapted for operating each of an electric motors 31 to 34 with a specific rotation speed. The electric motors 31 to 34 are operated such that each of the platform 21 and the circular rings 22 to 24 is rotated with a specific angular velocity.

The provision of separate electric motors 31 to 34 (Figure 1) has an advantage in terms of specific and variable adjustment of the angular velocity of each of the rotating components 21 to 24. Alternatively, the driving device 30 could comprise a single electric motor provided with multiple transmissions each having a predetermined transmission ratio and being adapted for driving the associated platform 21 or ring 22 to 24 with a predetermined angular velocity.

For the inventive method of generating a circular motion of a liquid in the chamber 10, in particular for creating a rotating liquid column in the chamber 10, the following steps are performed. Preparation steps comprise the provision of a sample and the filling of the chamber 10 with a liquid, e. g. water, a culture medium, or a reaction solution. The filling step may be conducted by accommodating the reaction device 10 with the sample carrier 40 in a container including the liquid.

After closure of the chamber 10 by setting it on the sample carrier and/or by closing any access opening in the walls, the spinning device 20 is driven to rotate the components 21 to 24 around the central z-axis. Due to the friction with the lower surfaces of the components 21 to 24, the liquid is subjected to a driving force, so that a liquid column rotating around the z-axis is created as a result of the inner friction in the liquid. As the platform 21 and the circular rings 22 to 24 are rotated with different angular velocities relative to the z-axis, a radial velocity profile can be induced in the liquid column.

For the preferred provision of a homogeneous shear stress distribution at the bottom of the chamber 10 adjacent to the surface of the sample carrier 40, the electric motors are controlled such that the angular velocity of the rotating components 21 to 24 is decreasing from the centre towards the outer boundary of the spinning device 20. In particular, the rotating platform 21 has the largest rotation speed compared with the other rotating components.

In a practical embodiment, the reaction device 100 can be provided with a radius R = 7.5 cm and a height h = 5 cm of the chamber 10, a thickness of the chamber walls d = 8 mm and rotations speed of the platform 21 and the rings 22 to 24 of 324 min^{-1} , 162 min^{-1}, 102 min^{-1} and 78 min^{-1}. In particular for applications in biology and chemistry, the dimensions of the reaction chamber can be reduced, so that the chamber has a radius below 2 cm and a height below 0.4 cm.

A second embodiment of the inventive reaction device 100 is illustrated in Figure 3. The reaction device 100 comprises the chamber 10, the spinning device 20 and the driving device 30, it is arranged on the sample carrier 40 for creating a rotating liquid column in the chamber 10 as described above. Contrary to the first embodiment of Figures 1 and 2, the second embodiment is illustrated with a larger number of circular rings. In this example, six circular rings 21, 22, 23, 24, 25, 26, 27 are concentrically arranged relative to the axis of the cylindrical chamber 10 (z-axis). A central platform is omitted. Each of the rings is carried in a sleeve bearing provided on the inner surface of the cover wall 11 of the chamber 10.

Contrary to the first embodiment of Figures 1 and 2, the driving device comprises multiple magnetic drives 36 (driving coils), which are connected with the power supply and control device 35. In this case, the rotating components of the spinning device 20 are driven by magnetic forces. To this end, the circular rings 21, 22, 23, 24, 25, 26, 27 preferably are made of a ferromagnetic material. As an alternative, the rotating components may be made of a plastic material into which magnetic particles are incorporated.

Figure 3 illustrates a further variant of the invention, wherein the rotating components provide a cone shape 28 (shown with dashed lines). Each of the circular rings 21, 22, 23, 24, 25, 26, 27 has a slanted side facing to the inner space of the chamber. The rings are dimensioned such that the slanted sides add to the cone shape 28. This cone shape can be provided with the remaining embodiments illustrated here as well.

As a further modification of the first and second embodiments of Figures 1 to 3, the inner surface of the side wall 12 may have a wall roughness-reducing characteristic. To this end, a wall roughness-reducing coating, or a polished surface can be provided on the inner side of the side wall 12. As an advantage, a deceleration of the outermost boundary of the liquid column in the chamber 10 by wall roughness is reduced.

A third embodiment of reaction device 100 is schematically illustrated in Figure 4. The structure with the chamber 10, the spinning device 20 and the driving device 30 is essentially the same like with the first or second embodiments. Additionally, the outermost ring 24 is provided with a perimeter sleeve 29. The perimeter sleeve 29 extends from the outermost ring 24 in parallel to the side wall 12. Advantageously, an additional driving force is applied to the liquid column so that a drop of the angular velocity at the outer boundary of the liquid column is partially or completely suppressed.

Figures 5 and 6 illustrate results of computational simulations of the shear stress in the inventive reaction device. In dependency on the radius coordinate r (scaled with the radius R of the chamber 10) essentially balanced shear stress curves are obtained for marine applications (Figure 5) and bio-engineering applications (Figure 6). The corresponding data of conventional devices according to Figures 7A and 8A are added with dashed lines. With the invention, about 93 % of the liquid column radius has a constant tangential velocity, which is essentially better than values of 72% to 83% obtained with conventional marine and cell-culturing devices, respectively.

The features of the invention in the above description, the drawings and the claims can be of significance both individually as well in combination for the realisation of the invention in its various embodiments.

Claims

1. Method of generating a circular motion of a liquid in a chamber (10), in particular for generating bottom shear stress and flow control in a chamber (10), comprising the steps of:
- providing a spinning device (20) rotating around a central axis (z) in the chamber (10), and
- subjecting the liquid to a driving force provided by the spinning device (20), so that a liquid column rotating around the central axis (z) is created,

characterized in that
- the spinning device (20) comprises at least two rotating components (21, 22, 23, 24, 25, 26, 27) concentrically arranged in contact with the liquid, wherein
- the rotating components (21, 22, 23, 24, 25, 26, 27) being rotated with different angular velocities.

2. Method according to claim 1, wherein
- the angular velocities are decreasing with increasing radii of the rotating components (21, 22, 23, 24, 25, 26, 27) so that a homogeneous shear stress is created on a bottom of the chamber (10).

3. Method according to one of the foregoing claims, comprising the step of
- rotating the rotating components (21, 22, 23, 24, 25, 26, 27) with at least one electric motor (31, 32, 33, 34) or at least one magnetic drive (36).

4. Method according to one of the foregoing claims, wherein
- the chamber (10) is a closed system and the liquid is free of supply inflow or discharge outflow.

5. Method according to one of the foregoing claims, wherein the rotating components comprise
- a central platform (21) and at least one circular ring (22, 23, 24), or
- at least two circular rings (22, 23, 24, 25, 26, 27).

6. Method according to one of the foregoing claims, wherein
- an outer boundary of the liquid column is driven by a rotating perimeter sleeve (28).

7. Method according to one of the foregoing claims, comprising the step of
- conducting an optical investigation of a sample arranged in the chamber (10).

8. Method according to one of the foregoing claims, wherein
- the rotating liquid column is used for applying a shear stress on a sample, which comprises a sediment surface, a cell culture or a solid phase reaction component.

9. Reaction device (100), in particular for subjecting a sample in a liquid to a predetermined shear stress, comprising:
- a chamber (10) accommodating the liquid, and
- a spinning device (20) rotating around a central axis (z) in the chamber (10),

characterized in that

- the spinning device (20) comprises at least two rotating components (21, 22, 23, 24, 25, 26, 27) concentrically arranged in the chamber (10),
- a driving device (30) is provided which is adapted to rotate the rotating components (21, 22, 23, 24, 25, 26, 27) with different angular velocities.

10. Reaction device according to claim 9, wherein
- the driving device (30) is adapted to rotate the rotating components (21, 22, 23, 24, 25, 26, 27) with angular velocities decreasing with increasing radii of the circular rings (21, 22, 23, 24, 25, 26, 27).

11. Reaction device according to one of the claims 9 to 10, wherein the spinning device (20) comprises
- a central platform and at least one circular ring, or
- at least two circular rings.

12. Reaction device according to one of the claims 9 to 11, wherein
- the driving device (30) comprises at least one electric motor (31, 32, 33, 34) or at least one magnetic drive (36).

13. Reaction device according to one of the claims 9 to 12, wherein
- the chamber (10) is a closed system.

14. Reaction device according to one of the claims 9 to 12, wherein
- the chamber contains inflow and outflow openings.

15. Reaction device according to one of the claims 9 to 14, wherein
- the spinning device (20) comprises a rotating perimeter sleeve (29) providing a circumferential skirt.

16. Reaction device according to claim 15, wherein
- the rotating perimeter sleeve (29) is fixedly connected with the outermost ring of the rotating components (21, 22, 23, 24, 25, 26, 27).

17. Reaction device according to one of the claims 9 to 16, wherein at least parts of chamber walls (11, 12) of the chamber (10) have optical transparency and/or a polished inner surface.

18. Reaction device according to one of the claims 9 to 17, wherein the spinning device (20) has a cone shape (28)..

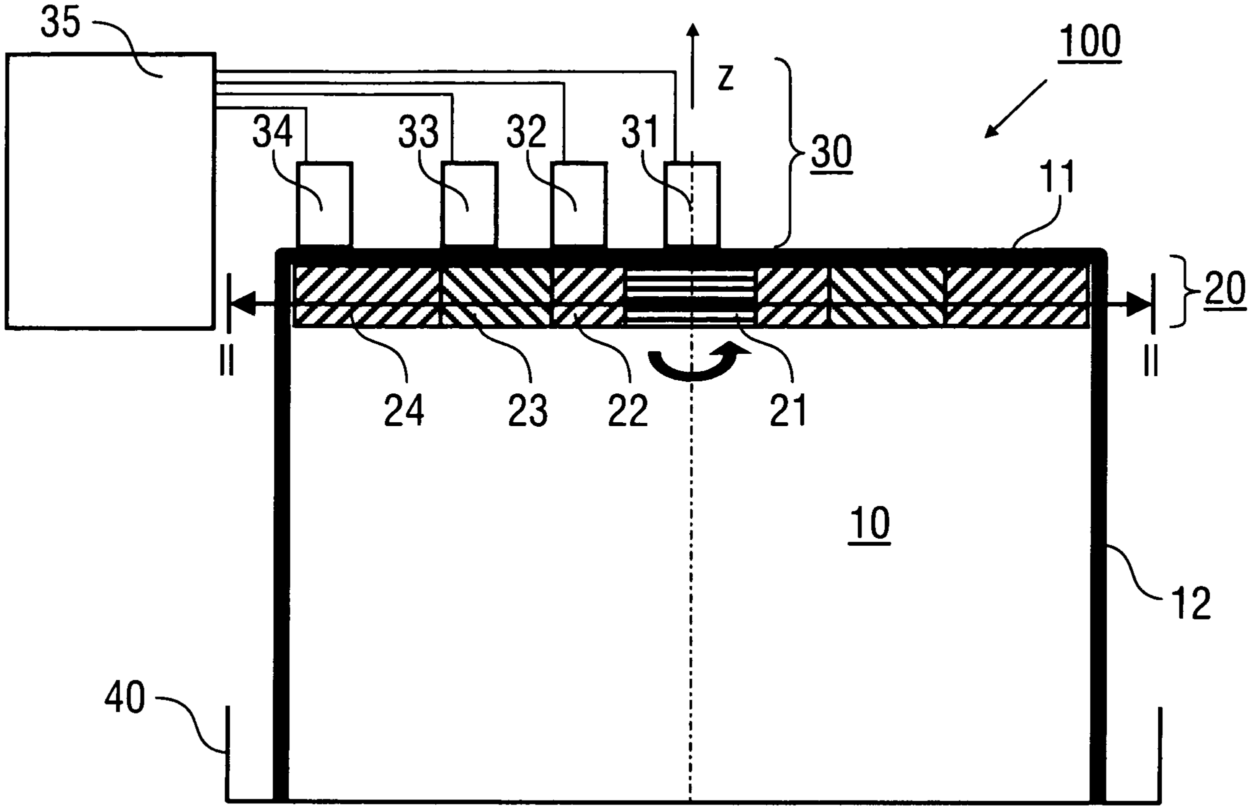

35
100
z
34
33
32
31
30
11
20
II
II
24
23
22
21
10
12
40

FIG. 1

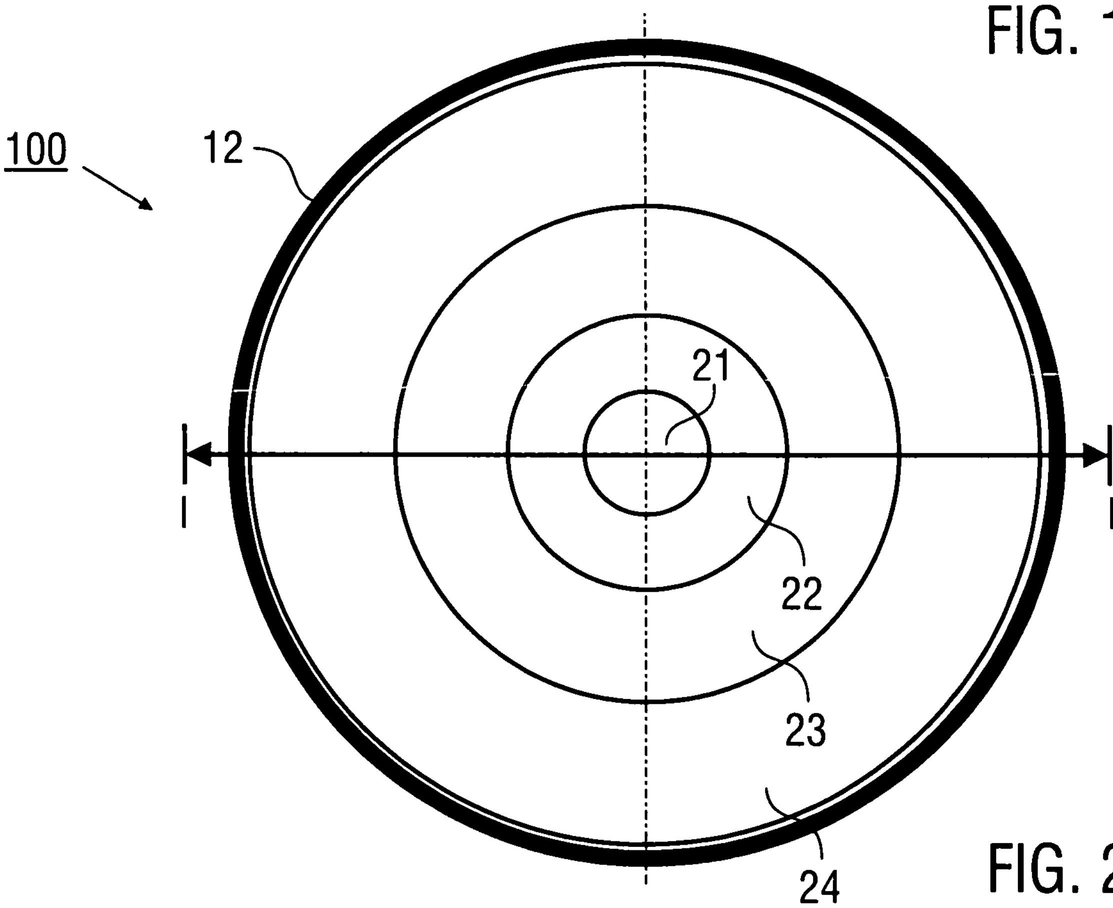

100
12
21
I
I
22
23
24

FIG. 2

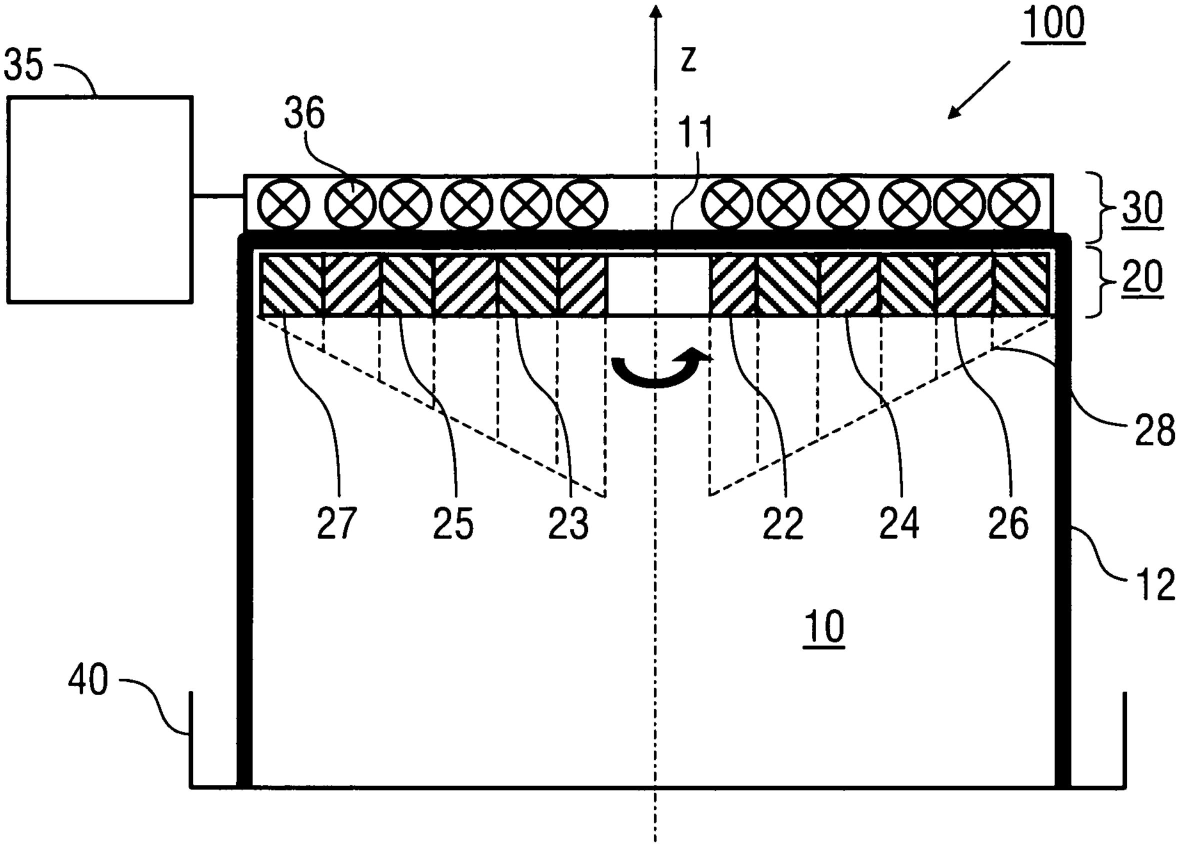


FIG. 3

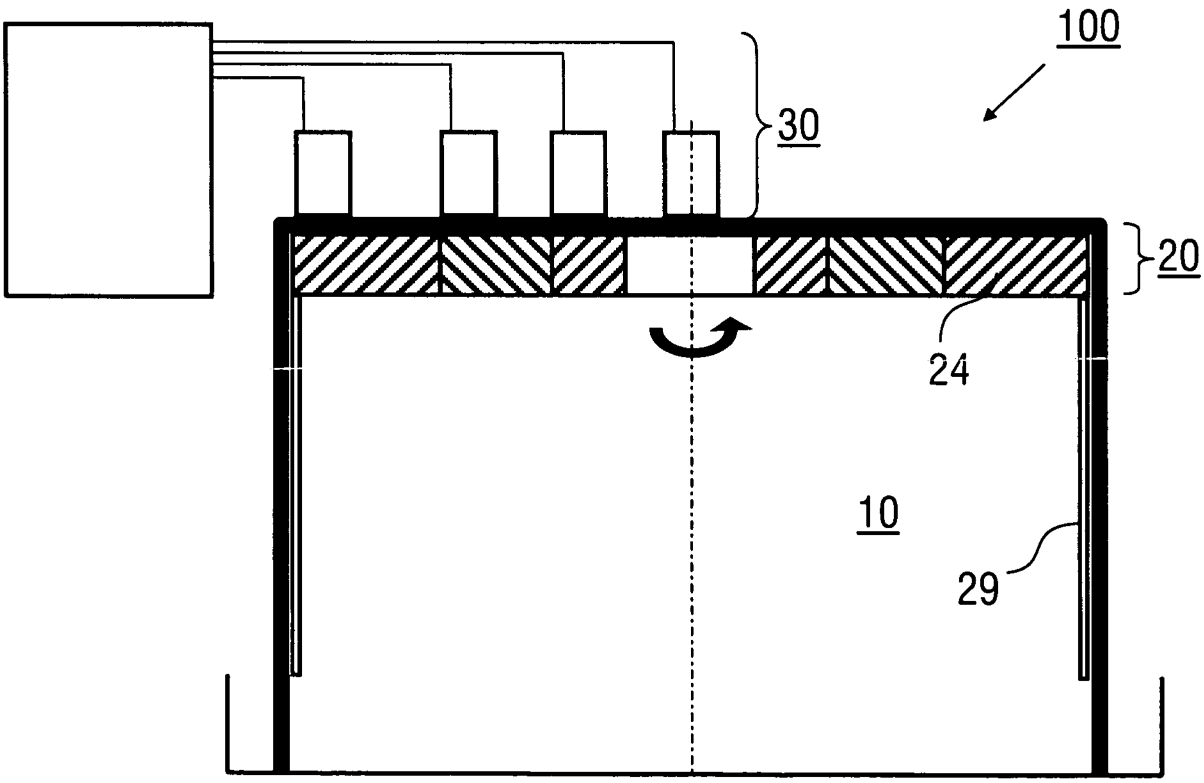
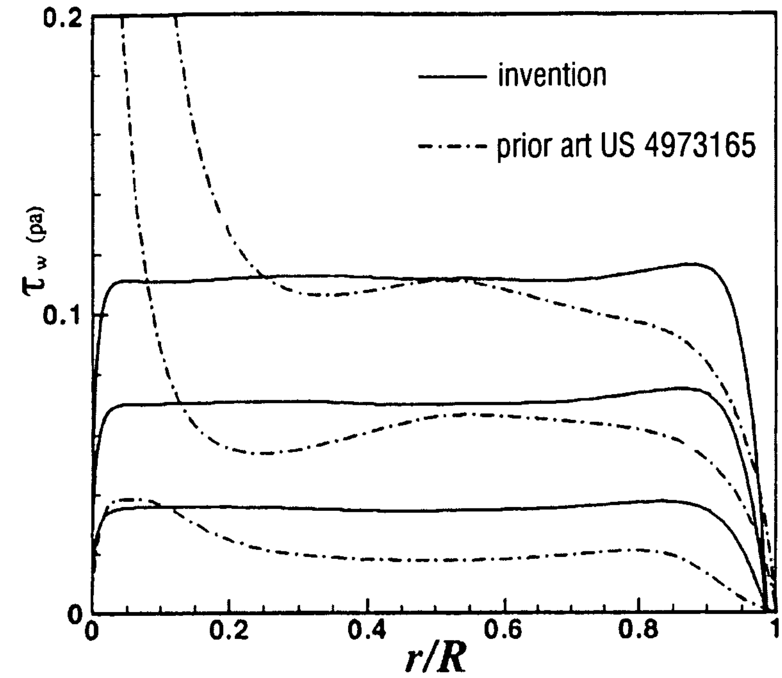
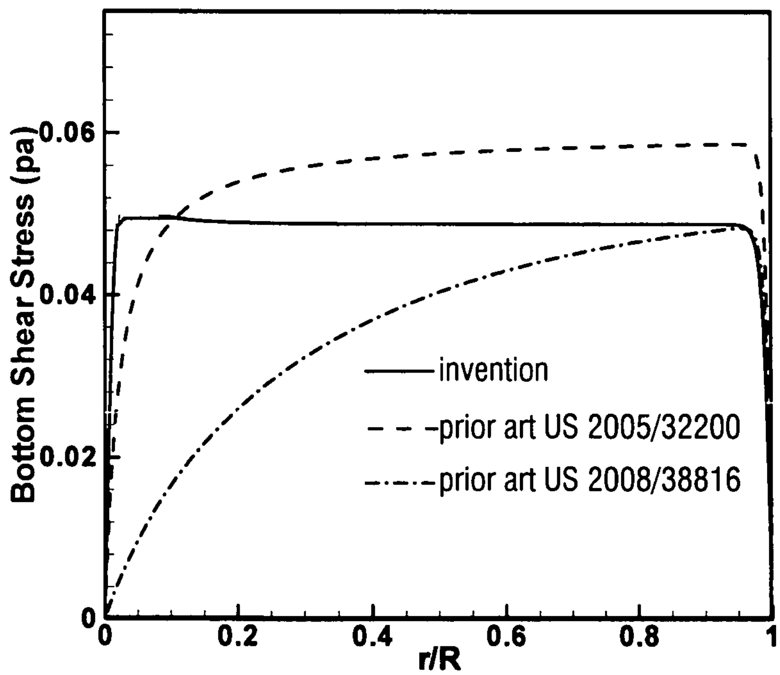


FIG. 4



0.2
0.1
0
τ_w (pa)
invention
prior art US 4973165
0
0.2
0.4
0.6
0.8
1
r/R

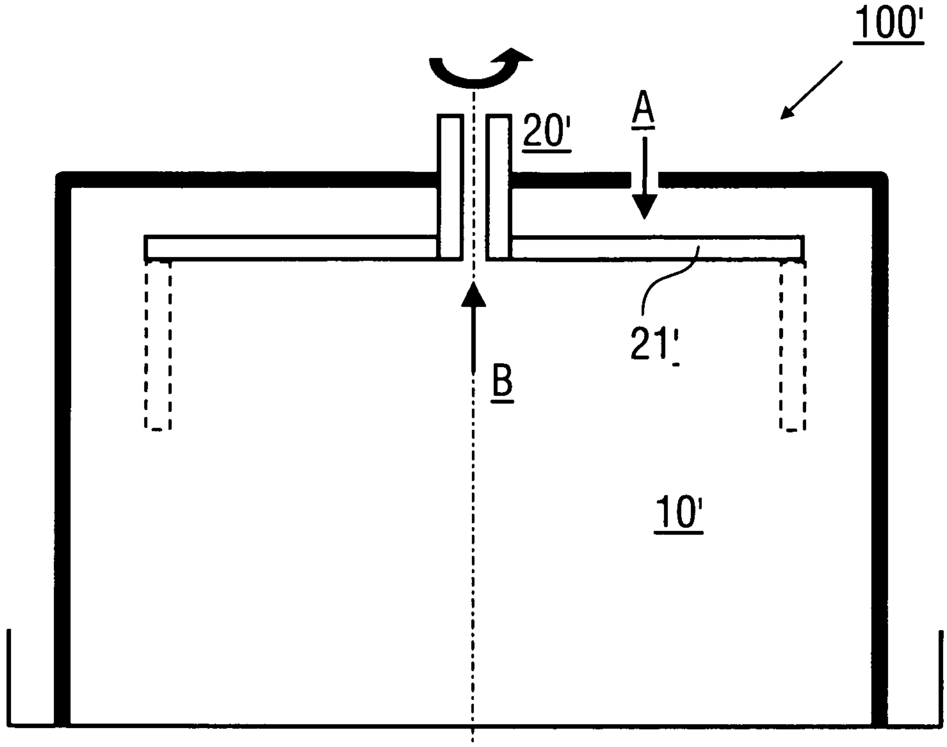
FIG. 5



0.06
0.04
0.02
0
Bottom Shear Stress (pa)
invention
prior art US 2005/32200
prior art US 2008/38816
0
0.2
0.4
0.6
0.8
1
r/R

FIG. 6

A



B

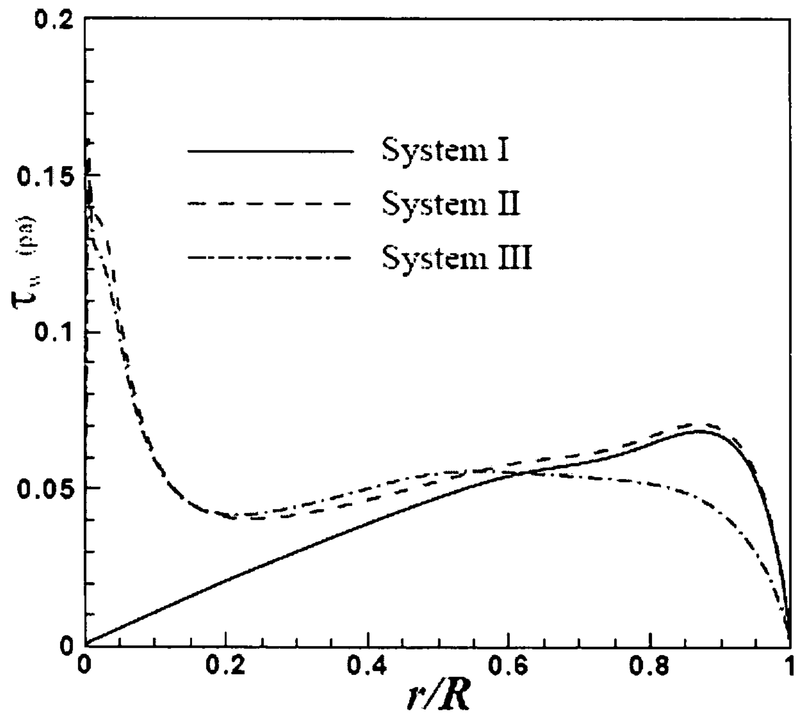
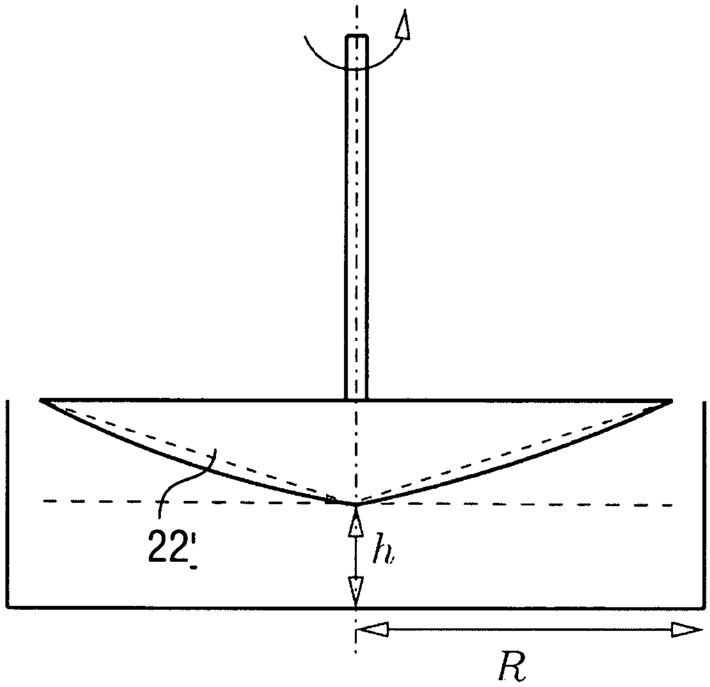


FIG. 7
(Prior Art)

A



B

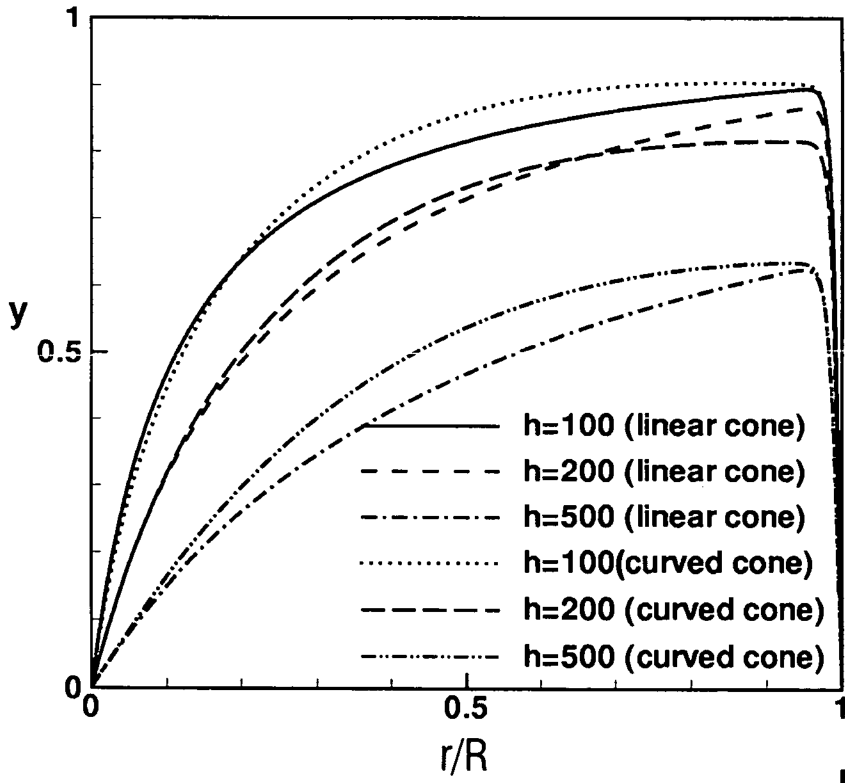


FIG. 8
(Prior Art)