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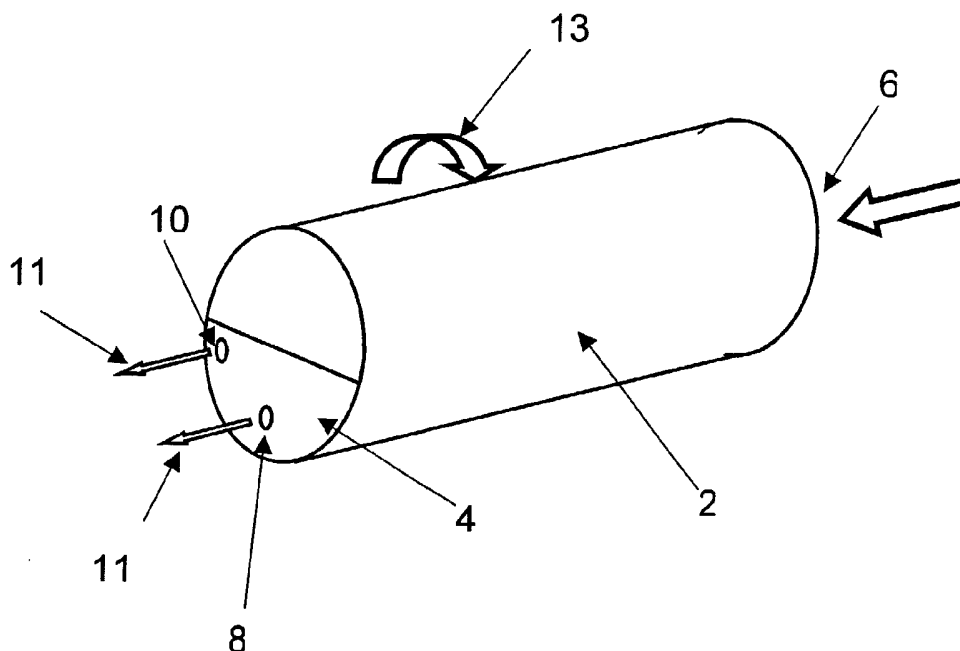
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[Continued on next page]

(54) Title: A METHOD AND DEVICE FOR SEPARATING PARTICULATE MATERIAL



(57) Abstract: A method of separating particulate material of differing size or density including the steps of: tumbling the particulate material to produce continuous or discrete avalanches (19) in the surface of the particulate material to move particles of smaller size (14) or higher density (22) towards the centre of the particulate material and particles of larger size (16) or lower density (24) radially outward from the centre of the particulate material; and extracting particles at selected radial locations (8, 10). A device for separating particulate material of differing size or density is also provided.



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A METHOD AND DEVICE FOR SEPARATING PARTICULATE MATERIAL

FIELD OF THE INVENTION

- 5 The invention relates to a method and device for separating particulate material. In particular, the invention relates to devices for classifying, sorting or filtering particulate material.

BACKGROUND OF THE INVENTION

10

The term "particulate material" refers to granular or powdered material such as sand, minerals, rock, gravel, grain, seed and other similar material.

- Sorting or classifying devices are used in a number of industries, such as the
15 construction, recycling and mining industries. These devices are used to separate particulate materials from other undesired substances based on the size of the particulate material. This type of classification is commonly done using screening techniques.

- 20 A known device for sorting particulate material takes the form of a rotary cylindrical screen having holes of a predetermined size with a series of rotating single row brushes located within the rotary screen. A screw auger feeds particulate material into the screen and the rotary brushes sweep the particulate material against the screens, causing particles below or at the predetermined size to fall through the
25 holes in the screen and particles larger than the predetermined size to pass along the screen for rejection.

- Sorting devices, including the known device, suffer from one or more of several disadvantages. In some devices, particles approaching the predetermined size
30 can wedge into the holes of the screen. This disrupts the sorting process as well as requiring frequent maintenance of those devices. Many existing sorting devices

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require screen replacement in order to vary the size of sorting particulate material. Particles hitting the screen in some devices, often at high speed, can cause damage and wear to the screen.

5 DISCLOSURE OF THE INVENTION

According to one aspect of the invention there is provided a method of separating particulate material of differing size or density, the method including the steps of:

- 10 tumbling the particulate material to produce continuous or discrete avalanches in the surface of the particulate material to move particles of smaller size or higher density towards the centre of the particulate material and particles of larger size or lower density radially outward from the centre of the particulate material; and
- extracting particles at selected radial locations.

15

According to another aspect of the invention, there is provided a device for separating particulate material of differing size or density, including:

- a rotatable vessel for receiving particulate material;
- means for feeding particulate material into the rotatable vessel;
- 20 means for rotating the vessel to tumble the particulate material, producing continuous or discrete avalanches in the surface of the particulate material to move particles of smaller size or higher density towards the centre of the particulate material and particles of larger size or lower density radially outward from the centre; and
- 25 means for extracting particulate material at selected radial locations.

As used in this specification term "avalanche" refers to continuous flow regimes or intermittent (discrete) flow regimes in which falling particles lift off the bed of material. Preferably, most of the bed of material is in solid body rotation with a relatively thin layer at the surface avalanching. The thin avalanching layer is not of
30 uniform thickness. For example in the continuous flow regime the thickness of the

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avalanching layer has a parabolic profile. In accordance with the present invention the average thickness of the avalanching layer in a non-cohesive material is typically about 5 particles and can be up to about 10 particles, although the depth of the avalanching layer depends on preferred rotation speed and, to a lesser extent, on particle properties.

Tumbling the particulate material to produce avalanches in the particulate material surface promotes the separation of particles according to their size or density. In the case of particles primarily of differing size the smaller particles tend to collect towards the centre of the particulate material while larger particles tend to collect at the boundary of the particulate material. Consequently a radial distribution of particles according to their size is created enabling extraction of particles of selected size by suitably positioned extraction devices. The present invention is not limited to separating materials of differing size that have the same density. Whilst in practice many applications of the invention involve separation of particles of differing size but similar density, differing density of particles can be accommodated. However, when the ratios of particle size to density fulfil a particular and limited relationship, the tumbling action will mix the particles fulfilling that relationship instead of separating those particles. This only occurs for the number of particles obeying the relationship and not all particles in the "charge" of particles in the device. In practice, the number of particles fulfilling this relationship is typically a few percent of the entire charge of particles.

In the case of separating particulate material primarily of differing densities, tumbling the material to produce avalanches promotes the separation of the material according to its densities. More dense particles tend to collect toward the centre of the particulate materials whilst less dense particles tend to collect at the boundary of the particulate material. Again this provides for separation by collection at a suitable radial location. Separation according to density has a number of applications including for example in the recycling industry to separate a mixture of insulation and copper wire. Thus, the present invention allows

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particles to be extracted according to their size or density without the difficulties associated with known devices. For example, the invention does not employ a screen to sort the particulate material. This means that there is no risk of particles wedging into the screen and disrupting the sorting process. In addition, particles
5 can be selected according to their size easily and conveniently by sampling the particulate material along its radius for the required size.

The method and device according to the invention provides for low energy consumption and does not require as much space as for known sorters using
10 conventional screens. Furthermore, the device according to the invention has a large turn down ratio, allowing the device to be shut down and restarted with ease.

The method provides for less wear on both the particles and the device. Particles are separated under rotation and gravity and so the particles do not strike
15 equipment at high speed. Particles tend to erode through inter-particle contact and not by contact with the device.

It is preferred that tumbling the particulate material produces a continuous or intermittent flow of particles along the surface. Particles are preferably extracted
20 at radial locations outward from the centre of the particulate material.

The rotating means preferably tumbles the particulate material to produce a continuous or intermittent flow of particulate material along the surface. Preferably, the extracting means is located such that it extracts particulate material
25 at radial locations outward from the centre of the particulate material.

Preferably, the extracting means is located adjacent to the rotatable vessel so that particles may be extracted along a radius of the particulate material. The extracting means may be in the form of a plate with one or more holes radially
30 located relative to the particulate material. The extracting means may have feeders near the holes for promoting the extraction of particles. In other forms of

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the invention the extracting means may include one or more augers or pneumatic suction lines.

Preferably, the rotation rate of the vessel satisfies the relationship:

5

$$\frac{\omega^2 L}{g} \leq 1$$

where ω is the rotation rate;

L is the diameter of the vessel; and

g is the acceleration of gravity.

10

It is preferred that particulate material is fed into the vessel to just below 50% of volumetric capacity. Preferably, the particulate material is fed into the vessel to 25% of volumetric capacity.

15 It is preferred that the rotatable vessel is tilted at an angle to the horizontal to promote the flow of particulate material through the vessel. Preferably, the rotatable vessel is tilted between 4° and 10° to the horizontal.

BRIEF DESCRIPTION OF THE DRAWINGS

20

To assist in the understanding of the invention, a preferred embodiment of the invention will now be described by way of example only, with reference to the drawings, of which:

25 **Figure 1** is a perspective view of a device for separating particulate material according to a preferred embodiment of the invention;

Figure 2 is a sectional view of the device of Figure 1 illustrating the method of separating particulate material;

30

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Figure 3 is an illustration of the principles of the method of separating particulate material as applied by the device of Figure 1.

Figure 4 illustrates the method when applied to separating particles according to
5 density;

Figure 5 shows schematically the particular relationship between particle size and density for which mixing occurs; and

10 **Figures 6(a) to 6(e)** show the separation of building sand according to size by the device of Figure 1.

BEST MODE FOR CARRYING OUT THE INVENTION

15 Referring to Figure 1, there is shown a device for separating particulate material in accordance with a preferred embodiment of the invention. The device comprises of a rotary longitudinal tube 2 having a fixed end plate 4.

An input 6 for receiving particulate material to be separated or sorted is located at
20 the opposite end of the tube 2 to end plate 4. Fixed end plate 4 functions as an output for the device and has two holes 8, 10 for extracting particles from the tube 2. The size and position of holes 8, 10 determine the size or density of particles to be extracted at each respective hole. The holes or openings 8, 10 in end plate 4 are placed at different radial positions depending on the desired cut-sizes or
25 fractions of particulate material to extract. One or several size fractions can be removed simultaneously. Small screw-feeders (not shown) near holes 8, 10 remove classified particulate material locally around the holes 8, 10 (as shown by arrows 11) and feed the classified streams away to receptacles or next processing stages, as required. Other types of extractors may be used instead of the screw-
30 feeders. Should particles of a different size be required, the end plate 4 can be easily replaced with holes of the required size. The number of holes in the end

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plate 4 may be varied according to requirements.

Figure 2 illustrates the device and method in operation. A "charge" of particle material 12 is placed into tube 2. As the tube 2 rotates (in the direction of arrow 13), the particulate or granular material will first support a slope 18 until the slope 18 exceeds a critical angle. Further rotation past this point initiates an avalanche of material, as indicated by arrow 19 in broken lines. This avalanche 19 takes the material in the upper half of the slope 18 and moves it to the lower half of the slope 18. During the avalanche 19, particulate material is spread out on the slope 18, causing smaller particles 14 to move or percolate downwards. As charge 12 is rotating as a solid body, the action of the avalanche 19 on the particles 14, 16 during their traverses of the avalanching region causes the particles of smaller size 14 to move towards the centre of the charge 12, instead of the bottom of charge 12. Similarly, particles of larger size 16 move towards the boundary of charge 12. Repeated avalanching rapidly segregates the entire charge 12 by size as shown in Figure 2. If the particle size is distributed over a continuum of values, then the sizes are segregated with the smallest particles 14 in the centre of the charge 12 and the largest particles 16 on the boundary of the tube 2 with a continuous radial gradation of sized particles.

20

The physical mechanism for the size segregation is described in more detail with reference to Figure 3. When stationary, granules or particles interlock in groups. During the avalanche 19, the moving groups of particles dilate, i.e. they move farther apart from each other. This dilation increases the average spacing between particles that in turn allows smaller particles 14 to percolate downwards under the influence of gravity. When not spherical, as drawn, large particles 16 can also be rotated up to the surface by the differential velocities in the avalanching layer. Consequently, repeated avalanches promote the separation of particles 14 and larger particles 16.

30

It can be seen that the rate of rotation of the tube 2 determines the rate of

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separation. If the rotation rate is slow, avalanches are discrete. If the rotation rate is faster then avalanches blend into one another forming a continuous flow. If the rotation rate is faster still, a cascading motion is produced in which particles are lifted off the surface of the charge. Such cascading motion or flow is not favourable to particle separation. Furthermore, if the rotation rate is too fast, centrifugal forces cause the particles to stick to the sides of the tube, preventing particle separation.

The rotation rate, and so the different types of separation, can be measured by the Froude number. The Froude number is defined by the following equation:

$$Fr = \frac{\omega^2 L}{g} \quad \dots (1)$$

where Fr is the Froude number;

ω is the angular velocity or rotation rate;
L is the tube diameter or radius; and
g is the acceleration of gravity.

A Froude number in the range of $Fr < 10^{-3}$ to 10^{-2} means that the rotation rate ω produces discrete avalanches. Generally, a transition from avalanching to continuous flow occurs over the range $10^{-3} < Fr < 10^{-2}$. A continuous flow regime is produced for Froude numbers up to $Fr = 10^{-1}$. Froude numbers in the range of $10^{-1} < Fr < 1$ means that the rotation rate ω generates a cascading motion of particulate material. Rotation rates of $Fr > 1$ produce centrifugal motion and particulate material ceases to separate.

The avalanching usually occurs at a thin surface layer of the charge of particulate material. While this layer is not uniform, it has been found that the number of particles in the surface layer averages between 5 and 10 particles. In addition, the shape of the surface layer varies according to the rotation rate. For a

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discrete avalanche regime, the surface layer is triangular in cross section, while for a continuous flow regime the surface layer become more parabolic in cross section with more material towards the middle.

- 5 It has been estimated that there are approximately 30 avalanches during one revolution of the tube 2 at 5 rpm. It has also been found that 5 revolutions of tube 2 at 3 rpm is sufficient to achieve full separation of particulate material at 25% capacity.
- 10 The device can be tilted at small angles to promote flow through the device. Typical angles of 4°-5° are generally sufficient to allow a suitable flow of material through the device for separation with an upper limit of 10°.

- The optimum filling for a tube with a circular cross-section is 25% capacity or one
- 15 quarter full as this promotes the most rapid segregation. Fill capacities of up to less than 50% may be used for the device but with lower rates of separation.

- In a continuous operation, feeder and extractor rates would be tied together to maintain a fill point around the optimum of 25% capacity. However, it may also be
- 20 desirable to allow wide variations from the optimum as this would mean the classifier equipment could also act as a "buffer" against unexpected material flows from upstream or downstream processing upsets.

- When very exacting separation within the fine component is the end goal, the
- 25 device may be used to remove the coarse component of particulate material rapidly and cheaply. Operated near its optimum fill with very rapid and complete segregation means that the device may be particularly apt for rapid, high-volume, first-pass, coarse segregation.

- 30 It has also been found that classification by density of particle gives a similar result, though from a somewhat different mechanism. Figure 4 shows the results

- 10 -

for a charge of particles 20 with a bimodal density distribution. The denser particles 22 will collect in the center of the charge 20 and the less dense particles 24 will collect at the boundary of the charge 20.

- 5 In some applications radial gradients of density and size difference introduce design criteria for the separating device. As exemplified by Figure 5, particles that are both large and dense in a particular ratio tend to mix instead of to separate. However, this mixing zone tends to be small, and in practice many industrial situations classify particles that do not vary greatly in density.

10

So far the preferred embodiments discussed have used particles with bimodal distribution of size or density. However, the device is not restricted in any way by property distributions. Figure 6 shows a cross section of a device according to the invention separating building sand according to size. Prior to starting, sand was
15 sifted into four groups of equal masses. The second largest sized group was painted (shown in white). The groups were remixed and poured into the device. Figure 6(a) is the initial condition and 6(e) is after 20 revolutions of the device at 3 rpm. As the sand particle size is distributed over a continuum of values, they are classified with the smallest particles in the centre of the charge and the largest on
20 the boundary of the container with a continuous radial gradation of sized particles.

An experiment was performed using the same device with the particulate material being salt. In this test the larger half of the salt size distribution had been dyed green. Classification was complete in the device after 3 revolutions at 2 rpm.

25

The foregoing describes only one embodiment of the invention and modifications can be made without departing from the scope of the invention.

Claims

1. A method of separating particulate material of differing size or density, the method including the steps of:
 - 5 tumbling the particulate material to produce continuous or discrete avalanches in the surface of the particulate material to move particles of smaller size or higher density towards the centre of the particulate material and particles of larger size or lower density radially outward from the centre of the particulate material; and
 - 10 extracting particles at selected radial locations.
2. The method of claim 1, wherein said tumbling produces a continuous or intermittent flow of particles along the surface.
- 15 3. The method of claim 1 or 2, wherein said tumbling causes avalanching of a relatively thin layer of said surface.
4. The method of claim 3, wherein said thin layer is not of uniform thickness.
- 20 5. The method of any one of claims 1-4, wherein particles are extracted at radial locations outward from the centre of the particulate material.
6. A device for separating particulate material of differing size or density, including:
 - 25 a rotatable vessel for receiving particulate material;
 - means for feeding particulate material into the rotatable vessel;
 - means for rotating the vessel to tumble the particulate material, producing continuous or discrete avalanches in the surface of the particulate material to move particles of smaller size or higher density towards the centre of the
 - 30 particulate material and particles of larger size or lower density radially outward from the centre; and

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means for extracting particulate material at selected radial locations.

7. The device of claim 6, wherein the rotating means tumbles the particulate material to produce a continuous or intermittent flow of particulate material along the surface.

8. The device of claim 6 or 7, wherein the rotation rate of the vessel satisfies the relationship:

$$\frac{\omega^2 L}{g} \leq 1$$

10 where ω is the rotation rate;

L is the diameter of the vessel; and

g is the acceleration of gravity.

9. The device of any one of claims 6-8, wherein the rotatable vessel is tilted at an angle to the horizontal to promote the flow of particulate material through the vessel.

10. The device of claim 9, wherein the rotatable vessel is tilted between 4° and 10° to the horizontal.

20

11. The device of any one of claims 6-10, wherein the extracting means extracts particulate material at radial locations outward from the centre of the particulate material.

12. The device of claim 11, wherein the extracting means is located adjacent to the rotatable vessel.

13. The device of claim 12, wherein the extracting means includes a plate with one or more holes radially located relative to the particulate material.

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14. The device of claim 13, wherein feeders are provided near said holes for promoting the extraction of particles.

15. The device of claim 12, wherein the extracting means includes one or more
5 augers or pneumatic suction lines.

16. The device of any one of claims 6-15, wherein that particulate material is fed into the vessel to just below 50% of volumetric capacity.

10 17. The device of claim 16, wherein the particulate material is fed into the vessel to 25% of volumetric capacity.

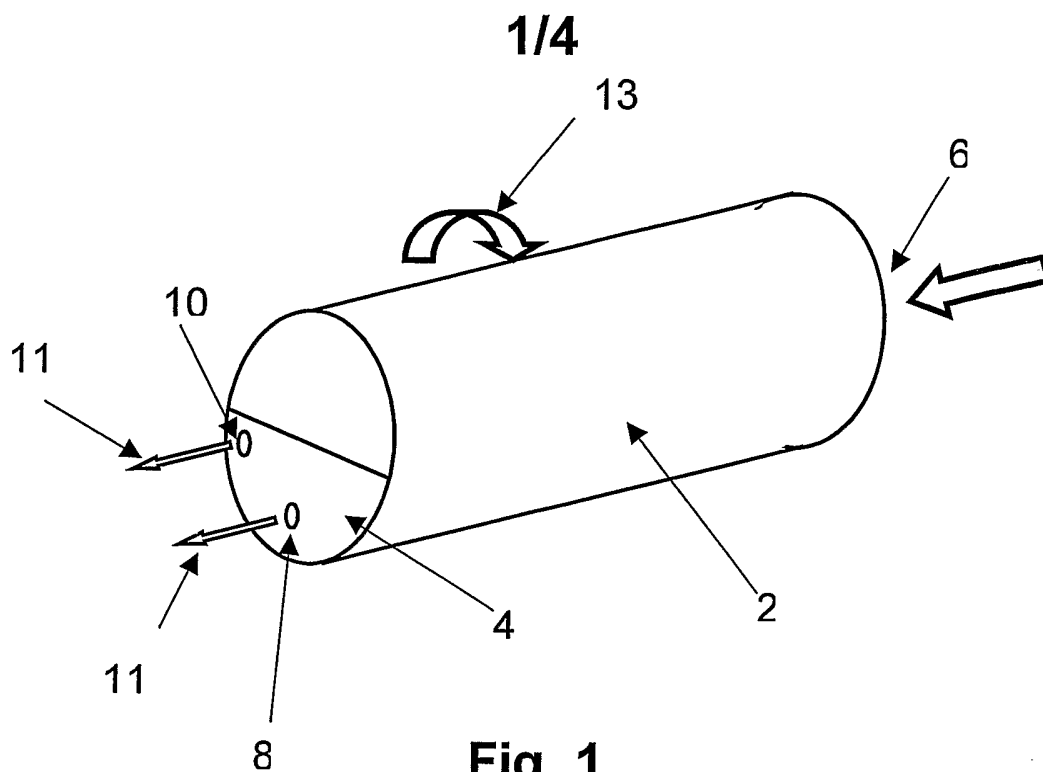


Fig. 1

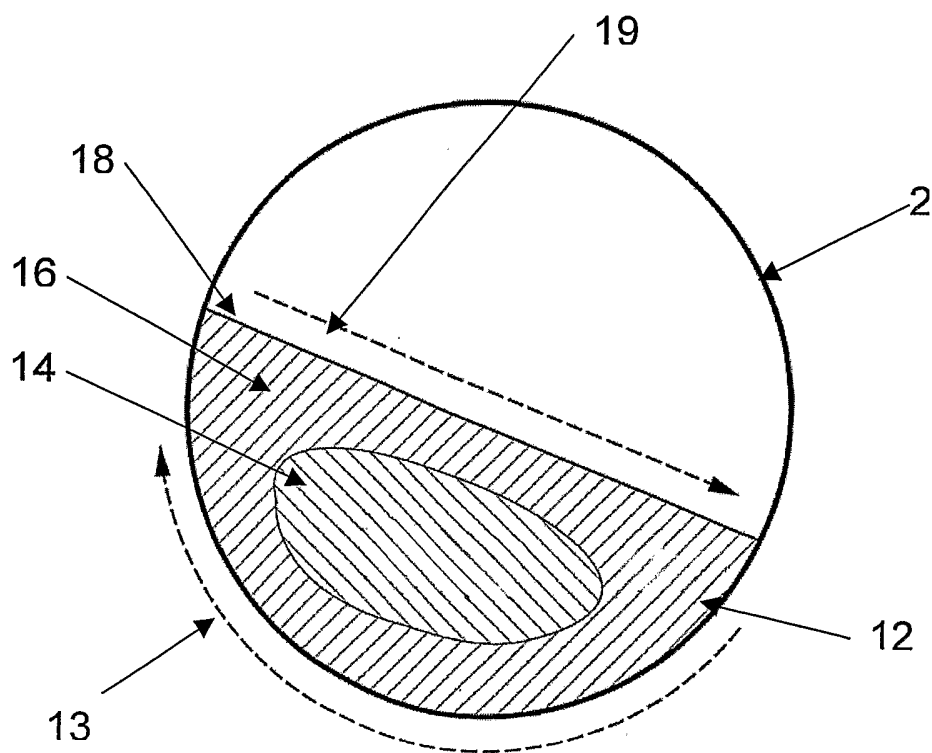


Fig. 2

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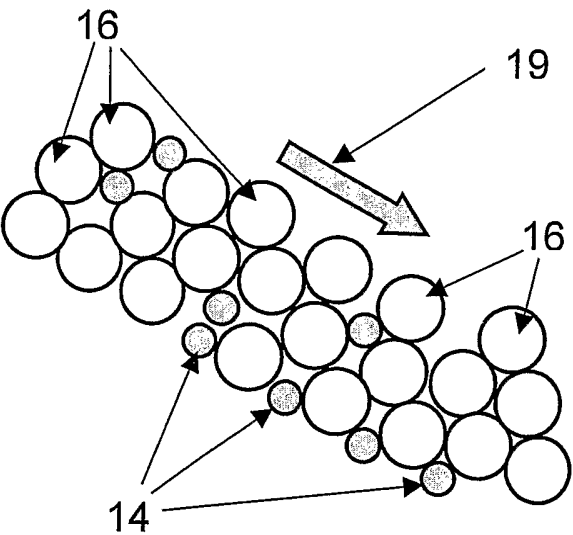


Fig. 3

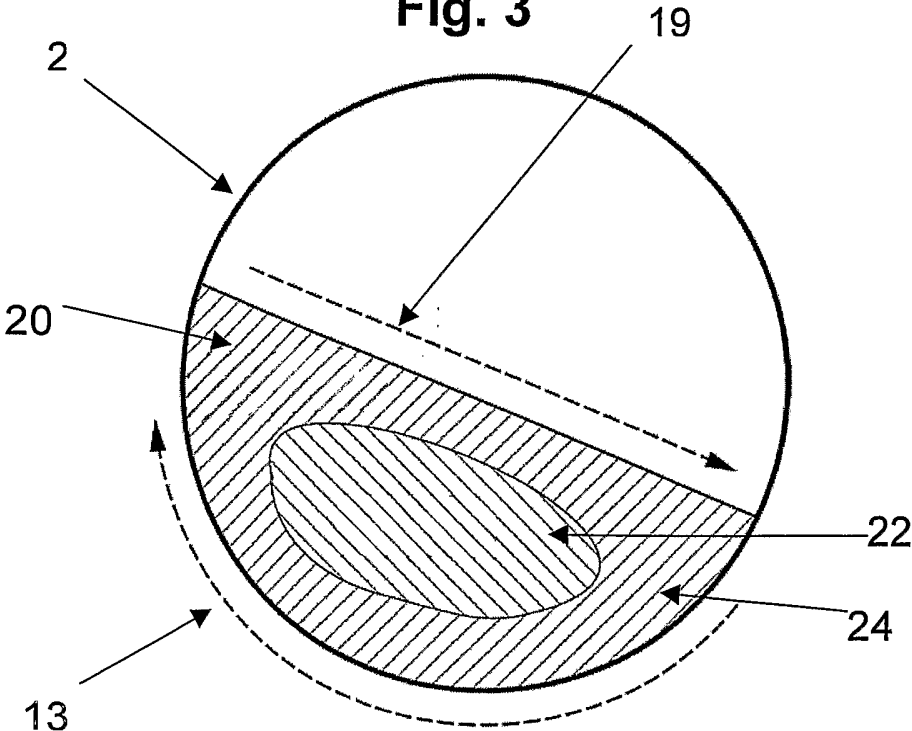
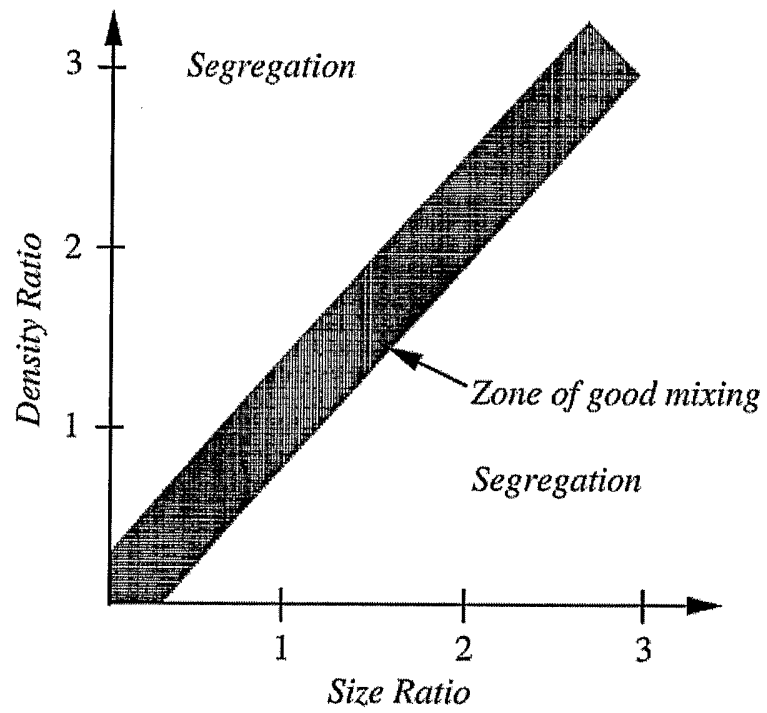
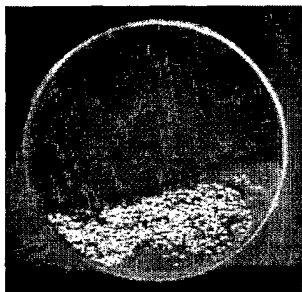


Fig. 4

3/4**Fig. 5**

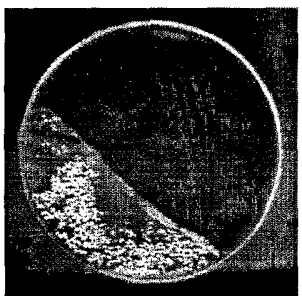
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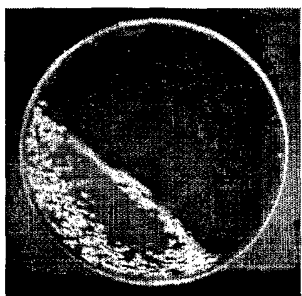
6(a) **Fig. 6**



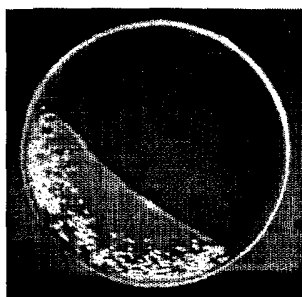
6(b)



6(c)



6(d)



6(e)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU02/01025

A. CLASSIFICATION OF SUBJECT MATTER												
Int. Cl. ⁷ : B07B 13/16, 13/08, 13/04, 13/00												
According to International Patent Classification (IPC) or to both national classification and IPC												
B. FIELDS SEARCHED												
Minimum documentation searched (classification system followed by classification symbols) IPC B07B 13/16, 13/08, 13/04, 13/00												
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched AU: IPC AS ABOVE												
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) WPAT : IPC B07B 13/- and Keywords (tumble, rotate, radial) and like terms												
C. DOCUMENTS CONSIDERED TO BE RELEVANT												
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.										
A	Derwent Abstract Accession No. 95-393714/51, Class J01, DE 4416756 A(KOCH TRANSPORTTECHNIK GMBH) 16 November 1995 abstract	1 - 17										
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Date of the actual completion of the international search 23 August 2002		Date of mailing of the international search report 29 AUG 2002										
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Information on patent family members

International application No.

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Patent Document Cited in Search Report	Patent Family Member
DE 4416756	NONE
END OF ANNEX	