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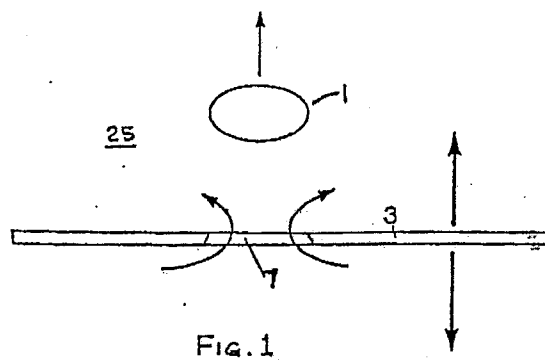
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Vortex ring mixers.

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The invention discloses mixing equipment including a plate having an orifice, and means for producing reciprocating relative motion between the orifice plate and the fluid at right angles to the orifice plate, to generate a ring vortex through the orifice, the orifice plate and orifice being positioned such that the ring vortex is projected into the fluid to be mixed.



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Description**VORTEX RING MIXERS****BACKGROUND OF THE INVENTION**

This invention relates to equipment for the mixing of fluids. The invention is particularly useful in, for example, mixing of stratified fluids and keeping in uniform suspension solid-fluid suspensions or solid-liquid slurries.

In the prior art, numerous devices using oscillating motion of a plate or conical or various geometry plates have been used to either mix fluids or act as a fluid diode and move or pump a fluid in a specific direction. Furthermore, an extremely large number of rotating or oscillating blade systems have been developed for mixing purposes. It has been proposed that vortex ring propagation can be used to enhance the penetrating effect of stack emissions to achieve better dispersion of stack emissions. Also devices employing ultrasonic or high frequency oscillations have been used to create localized mixing. However, none of the prior art devices are designed specifically to create ring or linear vortices for the purpose of efficient mixing of fluids. The relatively high frequency devices dissipate the majority of the input energy in heat created from the localized turbulence, whereas the present invention is relatively much more energy efficient while moving and mixing relatively large volumes of fluid, and is relatively insensitive to the fluid viscosity compared with most other devices.

Unlike the majority of mixing devices which intrude into the work or mixing volume, or require direct access to the mixing area, this device can be non-intrusive to the work area.

SUMMARY OF THE INVENTION

It is an object of the invention to provide improved mixing equipment.

Thus in accordance with the present invention there is provided mixing equipment including a plate having an orifice, and means for producing reciprocating relative motion between the orifice plate and the fluid at right angles to the orifice plate, to generate a ring vortex by passage of fluid through the orifice, the orifice plate and orifice being positioned such that the ring vortex is projected into the fluid to be mixed.

In accordance with one embodiment of the invention, an impulse chamber communicates via an orifice with a chamber containing fluid to be mixed. Means are provided for alternately increasing the volume of the impulse chamber and rapidly decreasing the volume of the impulse chamber to thereby rapidly force a fluid pulse through the orifice, thereby generating a ring vortex for propagation through the fluid to be mixed, to thereby mix the fluid.

In accordance with another embodiment of the invention, the orifice plate is reciprocated at right angles to the plane of the orifice plate within the container containing the fluid to be mixed.

The invention covers a range of mixing units, the primary mechanism of which is the pulsed ejection

of fluids through an opening or orifice. The frequency of pulsing, the volume of fluid ejected per pulse, orifice size and geometry, and proximity of orifices to other orifices and/or walls are all significant to the efficient operation of the mixer.

The invention primarily relates to equipment for the efficient mixing and maintenance of uniform or homogeneous distribution of fluids or solid-liquid suspensions. The primary mechanism is the impulsive movement of a slug of fluid or fluid-solid mixture from a location in close proximity to orifice opening(s) in the mixer, into the bulk of the fluid. The mechanism of this process is the generation of a ring vortex at the orifice(s) in the device. The motion of the vortex is such that the relative velocity of the fluid within the vortex ring, with respect to the fluid through which it is passing, is very small and therefore viscous effects are very small. Consequently, the dissipation of energy due to viscous forces and turbulence is relatively small, especially when compared with conventional mixing processes, such as mixers with propeller type impellers or circulatory pump systems. A further consequence of the low velocity differential or shear rate at the vortex ring to ambient fluid interface, is that this method can be used for the mixing of viscous fluid, such as slurries, non-Newtonian fluids and quite high viscosity fluids.

The primary objective of mixers or mixing processes is to mix or distribute the fluids such that a uniform distribution of the fluids or suspended solids is obtained with the least amount of energy consumption.

The equipment of the present invention uses the principle of the transport of material from the location of the mixer orifice in a direction normal to the plane of the orifice plate or orifice into the bulk of the fluid. Thus the primary objective of mixing processes is achieved by the distribution of fluid in a vessel, and in doing so it also generates a circulatory motion within the bulk of the fluid, which in turn creates a homogeneous dispersion of the fluid. Furthermore, some mixing occurs in the fluid behind the vortex ring. This is due to the fact that ambient fluid is continuously taken in at the rear of the ring. The fluid taken in is then mixed with the fluid in the ring. The majority of the fluid taken in is continuously dispersed from the ring after mixing and is then lost from the ring into the ambient fluid. This results in a dilution of the fluid in the ring, while producing some mixing in the wake of the ring during its passage through the ambient fluid.

In studying the characteristics of performance of these vortex mixers, various orifice geometries and extension tubes have been examined, as have been the pulsing mechanisms and the form of the pulse. It has been found that although the form of the lip of the orifice is not too important, the best shape is a circular hole with a sharp edge. However, a tubular orifice does produce reasonable ring vortices. Furthermore, an extension tube does not have too

critical an effect on the efficiency of the vortex generation. Various activation mechanisms, such as ratchets, cams, air cylinders, electric motors, electromagnetic and electric devices have been investigated and studied, and their feasibility depends, to a large extent, on the application for the unit and availability of the particular power supply and environmental conditions, such as pneumatic for explosive environments, and the type of power supply that is available.

Further features of the invention will be described or will become apparent in the course of the following detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

In order that the invention may be more clearly understood, the preferred embodiment thereof will now be described in detail by way of example, with reference to the accompanying drawings, in which:

Fig. 1 is a representation of various vortex ring generator configurations;

Fig. 1a is a representation of a flat plate vortex ring generator;

Fig. 1b is a representation of a diaphragm and piston type of vortex ring generator;

Fig. 2 is a schematic diagram of a pneumatically operated two-hole flat plate vortex ring generator;

Fig. 3a is a sectional view of a diaphragm operated vortex ring generator;

Fig. 3b is a sectional view of a piston operated vortex ring generator;

Fig. 4a is an illustration of a "T" end piece for dual vortex ring production;

Fig. 4b is an illustration of a 45-degree angle end piece;

Fig. 4c is an illustration of a right angle end piece for location of the mixer above a liquid surface;

Fig. 4d is an illustration of another right angle end piece;

Fig. 5a is a front view of an attachment unit for securing a diaphragm or piston type vortex ring generating mixer unit to the wall of a mixing tank;

Fig. 5b is a side sectional view of the attachment unit of Fig. 5a;

Fig. 6a is a front view of a portable unit;

Fig. 6b is a top view of the portable unit of Fig. 6a;

Fig. 7 is a front view showing an inverted installation of the portable unit;

Fig. 8 is a front view of a floating version of the portable unit;

Fig. 9 is a front view of an alternative portable unit;

Fig. 10 is a front view of an inverted installation of the alternative portable unit;

Fig. 11 is a front view of a floating version of the alternative portable unit;

Fig. 12a is a front view of another portable unit;

Fig. 12b is a top view of the portable unit of Fig. 12a; and

Fig. 13 is a typical graph of concentration

versus depth for a nominal lime slurry concentration of 22% by weight.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring first to Figs. 1, 1a, and 1b, the principle of the invention will be described briefly. An orifice plate 3 is shown, having an opening or orifice 7. The orifice plate 3 is disposed adjacent to or in the fluid 25 to be mixed (the container for the fluid is not illustrated). To generate the desired ring vortex 1 in the fluid to be mixed, the orifice 7 is moved relatively slowly towards the fluid 25, and then rapidly away from the fluid 25, as shown in Fig. 1a. Alternatively, as shown in Fig. 1b, a diaphragm or piston 2 is moved in a cyclic non-uniform motion to force fluid through the stationary orifice 7 into the fluid 25 to be mixed. The intake stroke of the piston, i.e. the stroke of the piston in the direction away from the fluid 25, is relatively slow. The expulsion stroke is very rapid. The form of the motion of the orifice, diaphragm or piston is very important for the efficient production of ring vortices. There is an optimum value of the ratio of the equivalent stroke length 'L' to orifice diameter 'D' for the most effective volume of fluid transport. The distance a ring will travel and the speed of travel are controlled by the velocity and motion of the orifice or diaphragm or piston.

Alternative embodiments of the invention are shown in Figs. 2 and 3. Fig. 2 shows an oscillating orifice plate device, corresponding to the principle described in Fig. 1a, whereas Fig. 3 shows a device employing a diaphragm or piston, corresponding to the principle described in Fig. 1b.

In Fig. 2 the orifice plate 3 is moved backwards and forwards using the rods 4 which are driven by drivers 5, which may be cams or pneumatic pistons. The orifice plate 3 is slowly moved in one direction normal to its surface and towards the fluid 25. This movement compresses the springs 6. The orifice plate drivers then release the orifice plate and the springs rapidly reverse the direction of the orifice plate. A ring vortex is then generated at each of the orifices 7, these vortices travelling in a direction opposite to that of the motion of the orifice plate 3. Fluid 25 adjacent to the orifices 7 on both sides of the orifice plate 3 is then drawn into the vortices 1 being generated. The vortices 1 then leave the orifices 7 with a linear velocity which is dependent on the movement and velocity of the orifices 7. The size and therefore the volume of the vortex, and therefore the quantity of fluid being transported, is a function of the stroke length of the movement of the orifice plate 3.

An alternative embodiment is shown in Figs 3a and 3b. A prime mover 8 pulls the rod 9, which in turn pulls a driver in the form of a diaphragm 10 (Fig. 3a) or piston 11 (Fig. 3b) away from the orifice or opening 7. The return spring 12 is compressed during this process. The rod 9 is then instantly released and the spring 12 rapidly forces the diaphragm 10 or piston 11 into the primary chamber 13. This motion rapidly forces the fluid in the primary chamber 13 through the orifice 7 and creates a ring vortex 1 which travels into the fluid 25. The return

velocity and stroke of the driver dictates the velocity of the propagation and volume of the vortex 1.

The form and stroke length of the motion of the orifice plate 3, diaphragm 10, or piston 11 is very important, in that it determines the efficient production of the ring vortices 1 and the volume of the fluid ejected. A sinusoidal motion of the generator is unsuitable since it produces strong secondary vortices which results in very poor vortex ring generation. The motion, frequency and stroke of the orifice or driver are very important in this device as are the location of the holes or orifices. The selection of a particular parameter depends on the dimensions of the mixing vessel or system, the location of the mixing device in the system, and the type of fluid to be mixed. The majority of these parameters and/or the stroke of the pneumatic piston can be adjusted on site and consequently the units are relatively universal.

The stroke of the rod 9 and therefore the volume of fluid discharged during each stroke is controlled using the adjuster 14 and the relaxed position adjuster nut 15. The relaxed position adjuster nut 15 is especially required when the unit is used with a pressurized tank or is located the bottom of a tank filled with a relatively dense fluid, since differential pressure on the diaphragm 10 will cause the diaphragm to be displaced from the normal relaxed position. The nut 14 is used to apply a force to the diaphragm 10 via the spring 12 and to counteract the unbalanced force on the diaphragm due to pressure on the mixing vessel side of the diaphragm. The zero position is indicated on the rod 9. An 'O' ring seal 16 stops any fluid leaking from the primary chamber 13 should the diaphragm 10 be ruptured.

Various exit orifice configurations and geometries can be used but the optimal shape of the orifice is circular. Optionally, extension tube configurations can be used, as shown in Fig 4. These orifice extensions can be employed with either device and are used to control the direction of a vortex. They may also be used to give considerable flexibility in the use and location of a device in a particular fluid field, such as the location of a device in the side wall, bottom or top of a mixing tank. Multiple hole extension tubes can be used to generate more than one vortex from one unit, which can be projected at various directions into the fluid media. This permits agitation and mixing in various directions and locations at the same time. The primary orifice opening 7 can be either immediately attached to the reservoir chamber 13 or be on an extension tube 17 which is attached to the chamber. The extension can have a single primary orifice or multiple orifices, as shown in Fig 4. The objective of the extension tube 17 is that the direction of the vortices can be controlled without undue intrusion into the mixing vessel or angular positioning of the mixer unit. The extension piece 17 can also be used to permit positioning of the mixer above a fluid. This permits the mixer unit to be located in the top of the fluid mixing vessel tank of reservoir and avoids the need for pressure seals between the fluid reservoir and the mixer unit.

The attachment of the mixer to a vessel is

achieved by the use of a collapsible attachment ring 18 which is shown Fig 5. Six collapsible leaves 18 situated around the periphery of the orifice piece 19 lie flat during insertion of the orifice piece into a hole 20 in the mixing vessel or tank wall 21. When the orifice piece 19 is screwed into the body of the mixer unit 22 the leaves open out, stopping the orifice piece from completely passing through the hole 20. A washer 23, which is between the mixing tank body 21 and the body of the mixer unit 22 stops leaking of the fluid from the primary chamber 13 of the unit and/or the mixing tank or vessel.

The motion and generation of a ring vortex is rather complex and difficult to accurately predict analytically. The mathematical modelling of the formation and subsequent motion of a ring vortex is quite complex and the effects of adjacent walls and orifices can be modeled using a complex mathematical approach based on a method of imaging. However, a number of quite simple semi-empirical equations have been developed which can be used in the design of these types of mixers.

A useful expression which was obtained empirically and which relates the equivalent plug length to the diameter of the orifice for efficient production of the ring vortices is:

$$1.5 \leq L/D_m \leq 3.5 \quad (1.1)$$

where D_m is the orifice diameter and L is the equivalent plug length given by:

$$L = 4V/\pi D_m^2 \quad (1.2)$$

and V is the volume displaced by the movement of the piston, diaphragm or orifice plate.

For an orifice plate, piston or diaphragm,

$$V = kAx \quad (1.3)$$

where x and A are the distance moved and the cross sectional area of the orifice plate, piston or diaphragm, and k is a constant for the deformation shape of the surface, i.e. $k = 1$ for a piston or a flat orifice plate, whereas for a diaphragm k depends on the surface shape which is dependent on the material and geometry of the diaphragm.

Virtually any value of L/D_m will result in the generation of a ring vortex but outside the range given by equation (1.1) the vortex ring will be of poor quality. The optimal value based on experimental data appears to be given by:

$$L/D_m < 2.8 \quad (1.4)$$

At the instant and immediately after the generation of a ring vortex the ratio of the translational velocity of the vortex ring U_v to the mean velocity of the slug of fluid passing through the orifice U_m is given by:

$$U_v/U_m \leq 0.6 \quad (1.5)$$

where U_m is given by:

$$U_m = U_p A / (\pi D_m^2) \quad (1.6)$$

where U_p is the velocity of the orifice plate or piston, or an equivalent velocity of a diaphragm. For relatively small distances, U_m is constant, and therefore the time t for a vortex ring to reach the surface or travel a distance H is:

$$t = H/U_v \quad (1.7)$$

The growth of a vortex ring is virtually independent of the fluid properties and an approximate empirical equation for the growth was established for the growth at the formative stages to be:

$$D/D_m = [1.1 + 0.36(L/D_m)]^{1/3} \quad (1.8)$$

That is, for the optimal condition when $L/D_m = 2.8$

$$D/D_m = 1.282 \quad (1.9)$$

This equation indicates the quantity of material being initially taken up into the vortex in the vicinity of the orifice, and consequently being transported to the surface or distant regions of the fluid being mixed.

In general:

$$V = [k\pi/6][1.1 + 0.36(L/D_m)]D_m^3 \quad (1.10)$$

where k is the correction for non-sphericity of the ring and is approximately 1.45. Therefore at the optimal condition,

$$V = 1.1kD_m^3 \quad (1.11)$$

or

$$V = 1.6D_m^3 \quad (1.12)$$

Consequently, the minimum number of strokes or pulses of the mixer mechanism required to mix the volume of fluid V_f is

$$N = V_f/V \quad (1.13)$$

or

$$N = V_f / (C[k\pi/6][1.1 + 0.36(L/D_m)]D_m^3) \quad (1.14)$$

or at the optimal condition,

$$N = 0.625 V_f / D_m^3 \quad (1.15)$$

which is the minimal value for the number of strokes to initially mix a fluid.

The time T to establish the initial mixed condition is therefore,

$$T = N/f \quad (1.16)$$

where f is the stroke frequency. The frequency required to maintain a mixed condition obviously depends on the type of material(s) being mixed. However, in a simple two fluid system in which the density difference is relatively small (that is, a density ratio of less than 1.1), it has been found that a frequency of 0.25 Hz was quite adequate. However for slurries such as lime, in which the density ratio between the particles and the fluid can be as high as 3.0, as high a frequency as practical should be used. It was found that a frequency of about 0.4 Hz was adequate for a lime slurry with a weight concentration of 24% and a density ratio of 2.29. Frequencies of greater than about 0.6 Hz may result in the ingestion of secondary vortices into the orifice and excessive localized turbulence which results in the generation of a weak primary vortex ring. This to a large extent can be controlled by the use of a stroke characteristic such that there is a relatively fast intake stroke followed by a dwell period with a fast return or vortex generation stroke. For these reasons a sinusoidal motion of an orifice, diaphragm or piston has been found to not be desirable for the efficient generation of vortices. This also avoids excessive generation of localized turbulence which can also affect the efficient generation of vortex rings.

The distance between adjacent orifices, and orifices and adjacent walls, is quite critical, since walls and other vortices can cause vortices to collide with each other or a wall before they have travelled any appreciable distance. A semi-empirical analysis found that the minimum reasonable distance between the centres of adjacent orifices to be given by:

$$X/D_m \geq 2.5 \quad (1.17)$$

where X is the centre to centre distance between the orifices. Alternatively, the minimum reasonable wall

to orifice centre distance can be given by:

$$X/D_m \geq 2.0 \quad (1.18)$$

It is difficult to predict the distance that a vortex will travel before it disintegrates, and it depends on a number of factors, such as whether it is initially stable or unstable, laminar or turbulent. It also depends on the initial velocity of the vortex U_v , and any density differences between the fluid initially in the ring at its formative stages and the ambient or bulk of the fluid to be mixed. But it is relatively insensitive to the fluid's viscosity or whether the fluid is Newtonian or non-Newtonian, since the shear and drag forces are relatively insignificant in the motion of a vortex ring. However, vertical distances of 2m in a 24% by weight aqueous lime suspension were achieved with the ring still very energetic when it broke the liquid surface, and in water solutions vortices travelled vertically 1.3m and then continued to travel in the air over 1m after leaving the surface of the water. On the basis of qualitative observations it is felt that distances of over 10m would not be unreasonable when the density difference is not too great, such as ≤ 1.1 .

Figs. 6a and 6b show a portable unit which has two or three pneumatic pistons 26 which operate a moving orifice plate 3 with centrally located orifice 7. The orifice plate is located in a cylindrical housing 28, open at one end, the housing acting as an anchor for the moving orifice plate. The orifice plate moves back and forward inside the cylindrical body in a controlled motion and generates vortices through the orifice. The orifice plate is moved by the two or three pneumatic cylinders. The actual motion of the orifice plate must be specifically controlled to achieve the most efficient results for various liquids and suspensions. This control is achieved by the combination of an air valve 29 and electric circuit 30. This unit or device is portable can be large or quite small and the outer diameter D of the orifice plate compared with the orifice diameter d is such that there will be no violation of the spacing requirement between the use of more than one unit in a mixing vessel or the distance from the orifice to a wall. This unit can be used upside down, Fig. 7, such that the vortices are projected downwardly. The distance the vortex rings will travel is 100 to 200 orifice diameters and therefore with an orifice diameter of for example six inches it is expected that the vortex ring will travel between 50 and 100 feet depending on the fluids involved and the situation. The unit can be supported by the adjustable support bar such that the actual unit is kept at or near the liquid surface, or at any required depth in the liquid being treated. Furthermore, by the introduction of a small controlled air vent 31, air may be admitted to the unit. When used in the upside-down configuration, air can be admitted to the unit and a highly aerated vortex ring is emitted from the unit and projected down into the liquid media. This operation has been tested and found to result in very efficient aeration of a fluid and therefore the unit can be used as a very efficient aeration unit, and could be used for the aeration and destratification of lakes or large bodies of liquids. An alternative arrangement is to float the device in an inverted manner on the surface of the liquid being

treated using a flotation tank 32, as shown in Fig. 8. The operating pistons are located inside the flotation tank.

Another alternative arrangement of the device is with the cylindrical wall removed as shown in Fig. 9. This results in radial discharge of the liquid as well as the projection of a vortex ring. This arrangement has been tested and gives excellent mixing performance. The diameter ratio d/D is important when considering the mixing vessel geometry. Relatively small d/D ratios are necessary when the vortex ring is required to travel large distances. The diameter of the base plate 40 is larger than that for the unit having side walls. Fig. 10 shows this alternative arrangement inverted and supported on an adjustable support bar 33. Fig. 11 shows basically the same unit but with a flotation tank with the pistons 26 inside the tank. This unit in the regular or inverted mode with radial flow can be of considerable value for various systems and liquids.

If it is required that the ring vortices travel large distances, then the sidewall configuration is used to induce a high energy to the vortex ring. However, if there is a need for considerable agitation in the vicinity of the plate then the side wall is removed to permit some radial flow of the fluid.

A third unit shown in Figs. 12a and 12b is also a portable unit. This unit has a vortex generating orifice plate 3 which is activated by two rods 34, which are in turn activated by a single rod 35 from a pneumatic piston 36. The piston and associated air valve 29 and control circuit 30 are either attached to a supporting cross bar or can be attached to a cover plate for the fluid container. If the mixer is to be used for an explosive or flammable liquid and an electrical control system is used, the electrical controller can be located in a separate control box located remote from the mixer. However, a totally pneumatic control system is normally employed for flammable or explosive fluids. This unit can vary both the pressure and therefore the force of the agitation and also the frequency of the agitative cycle. The unit can be used in a similar manner to conventional mixers, that is with the primary energising unit located outside the mixing vessel as compared with the immersed units described above.

Fig. 13 shows a typical graph of percentage concentration versus percentage depth for a flat orifice plate vortex mixer located in the bottom of a 0.6m wide by 1.22m long by 1.83m depth tank of lime having a nominal concentration by weight of 22%. It was noted that the variation of the slurry concentration was less than 2% over the entire volume of the slurry. The mean particle size was approximately 10 microns with a mean specific density of 2.2, and each data point represents the mean of several samples taken at various representative locations, including near wall locations, in a given strata. The vortex generating orifice plate mixer was located 0.1m from the floor of the mixing vessel and had two equally spaced 0.2m diameter holes. The orifice plate driving mechanism was a cam having a maximum lift of 0.25m and the frequency of operation was 0.4 Hz. A variable speed 1.12 kW d.c. electric motor in conjunction with a reduction gearing was used to

drive the lifting cam.

The equivalent mass of the orifice plate and associated moving equipment including spring forces and allowing for buoyancy was approximately 133kg. Therefore, since the intake or upstroke is the primary stroke involving input power to the mixer diaphragm, piston or orifice plate, the actual power used in lifting the orifice plate through 0.025m with a frequency of 0.4 Hz was 13.25W, which even allowing for a 50% loss for the drive system and therefore an extra 50% during the down or expulsion stroke, the power input would have been 26.5W. The volume of the lime slurry was 1.36m³, and therefore the specific input power was less than 0.02 W/L, which may be compared with 0.5 W/L to 1.0 W/L for many conventional mixers.

Under these circumstances the volume leaving the orifice plate per hole per stroke is 0.007m³, and therefore for a slurry volume of 1.361m³ it theoretically should require a minimum of 98 strokes of the orifice plate or a time of 4.08 minutes to initially mix the slurry. Actual experiments with aqueous lime suspensions of up to 10% concentration, using five sampling locations distributed throughout the mixing volume, indicated that between 100 and 150 strokes were required to create a homogeneous suspension from start up, depending on the operating conditions. This result is in good agreement with the above theoretical estimation. It is difficult, when taking samples to accurately assess when complete mixing has occurred, however it was estimated to be less than 10 minutes and under the circumstances favorably agrees with the semi-empirical estimate.

Various fluids have been used as the medium to be mixed such as lime slurries of up to 24% by weight, aqueous coal slurries with concentrations of up to 25% by weight, stratified aqueous-salt solutions, and other substances with densities similar to that of water. There should be no problem in mixing fluids from gases to relatively dense liquids. However, the possibility of mixing slurries with solids having specific densities of up to 3.0 depends on the particle size and size distribution. If the specific density of the particles is quite high compared with the suspension fluid then large particles will tend to settle or precipitate out of the suspension. It is difficult to exactly assess the size and density conditions for settling, but the settling velocity applicable to any suspension must apply. That is, the local fluid velocity in the vortex ring and the surrounding fluid must be greater than the settling velocity of the particular particles, and depends on particle size, density and suspension fluid viscosity. That is, if the velocity within the vortex is not greater than the required velocity to avoid settling, then the particles will not be kept in suspension. This can be partly overcome by increasing the orifice plate velocity and frequency. But slurries containing relatively large sand particles would be very difficult to keep in suspension. However, as the particle density approaches that of the suspension fluid, then the particle size will have little effect on the efficiency of the mixing process, when using a vortex ring mixer.

It will be appreciated that the above description

relates to the preferred and alternative embodiments by way of example only. Many variations on the invention will be obvious to those knowledgeable in the field.

Claims

1. Equipment for mixing fluids, characterized by a plate (3) having an orifice (7), and driving means (5) for producing reciprocating relative motion between said orifice plate (3) and said fluid (25) at right angles to said orifice plate, to generate a ring vortex (1) through said orifice, said orifice plate and orifice being positioned such that the ring vortex is projected into the fluid to be mixed.

2. Mixing equipment as recited in claim 1, further characterized by an impulse chamber (13) adapted for communication with a chamber containing fluid (25) to be mixed, said impulse chamber being separated by said orifice plate (3) from said chamber containing fluid to be mixed, and means (2) for alternately increasing the volume of said chamber and rapidly decreasing the volume of said chamber to thereby rapidly force a fluid pulse through said orifice in said orifice plate, thereby generating a ring vortex for propagation through said fluid to be mixed, to thereby mix said fluid.

3. Mixing equipment as recited in claim 2, further characterized by said means for alternately increasing and decreasing the volume of said impulse chamber comprising a piston (11) reciprocating within said impulse chamber.

4. Mixing equipment as recited in claim 3, further characterized by a prime mover (8) for driving said piston (11) to increase the volume of said impulse chamber, a return spring (12) positioned to force said piston rapidly to decrease the volume of said impulse chamber, and means to disengage said prime mover from said piston to permit said return spring to act after said volume increase and to re-engage said prime mover to said piston after the action of said return spring in rapidly decreasing said volume.

5. Mixing equipment as recited in claim 2, further characterized by said means for alternately increasing and decreasing the volume of said impulse chamber comprising a flexible diaphragm (10) positioned across said impulse chamber and constituting a boundary thereof, the outer periphery of said diaphragm sealingly engaging said impulse chamber, said volume-varying means further comprising means connected to said diaphragm for reciprocating said diaphragm to change the impulse chamber volume.

6. Mixing equipment as recited in claim 5, further characterized by a prime mover for driving said diaphragm-connected means to increase the volume of said impulse chamber, a

return spring positioned to force said diaphragm-connected means rapidly to decrease the volume of said impulse chamber, and means to disengage said prime mover from said diaphragm-connected means to permit said return spring to act after said volume increase and to re-engage said prime mover to said diaphragm-connected means after the action of said return spring in rapidly decreasing said volume.

7. Mixing equipment as recited in claim 2, further characterized by the portion of said impulse chamber in which said orifice is defined being moveable with respect to the rest of the impulse chamber, said moveable portion constituting said means for alternately increasing and decreasing the volume of said impulse chamber, and including means for reciprocating said moveable portion.

8. Mixing equipment as recited in Claim 7, further characterized by a prime mover for driving said moveable portion to increase the volume of said impulse chamber, a return spring positioned to force said moveable portion rapidly to decrease the volume of said impulse chamber, and means to disengage said prime mover from said moveable portion to permit said return spring to act after said volume increase and to re-engage said prime mover to said moveable portion after the action of said return spring in rapidly decreasing said volume.

9. Mixing equipment as recited in claim 1, characterized by a housing (28) open at one end, positionable in a container containing fluid to be mixed, said orifice plate being mounted in said housing parallel to said open end, said driving means being mounted to drive said orifice plate with respect to said housing.

10. Mixing equipment as recited in claim 9, further characterized by flotation means (32) associated with said housing, for floating said housing on the surface of said fluid with said open end facing downwardly into said fluid.

11. Mixing equipment as recited in claim 1, characterized by a base plate (40) positionable in a container containing fluid to be mixed, said orifice plate being mounted parallel to said base plate, said driving means being mounted to drive said orifice plate with respect to said base plate.

12. Mixing equipment as recited in claim 11, further characterized by flotation means associated with said base plate, for floating said base plate at the surface of said fluid with said orifice plate beneath it.

13. Mixing equipment as recited in claim 1, characterized by an orifice plate positionable in said fluid to be mixed, in which said driving means are positionable outside said fluid, connected to said orifice plate via rods (34) to drive said orifice plate.

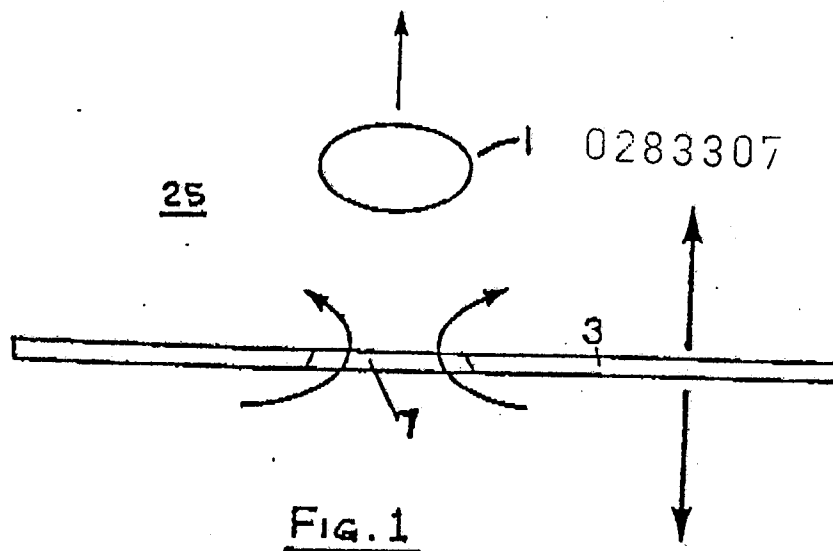


Figure (1a)

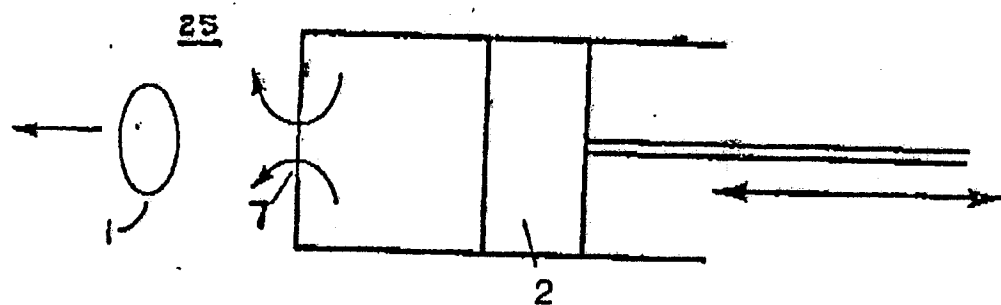
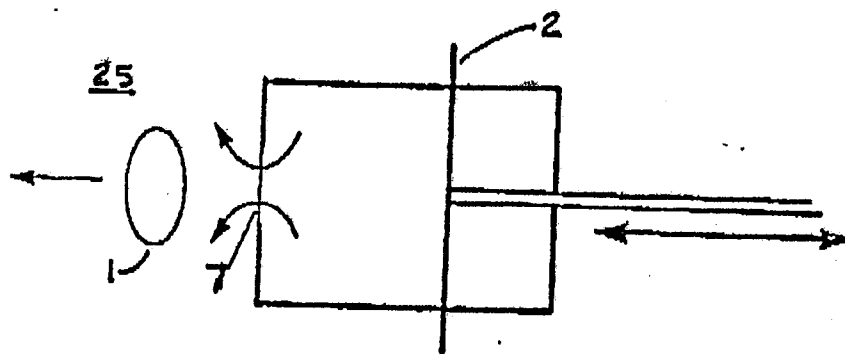
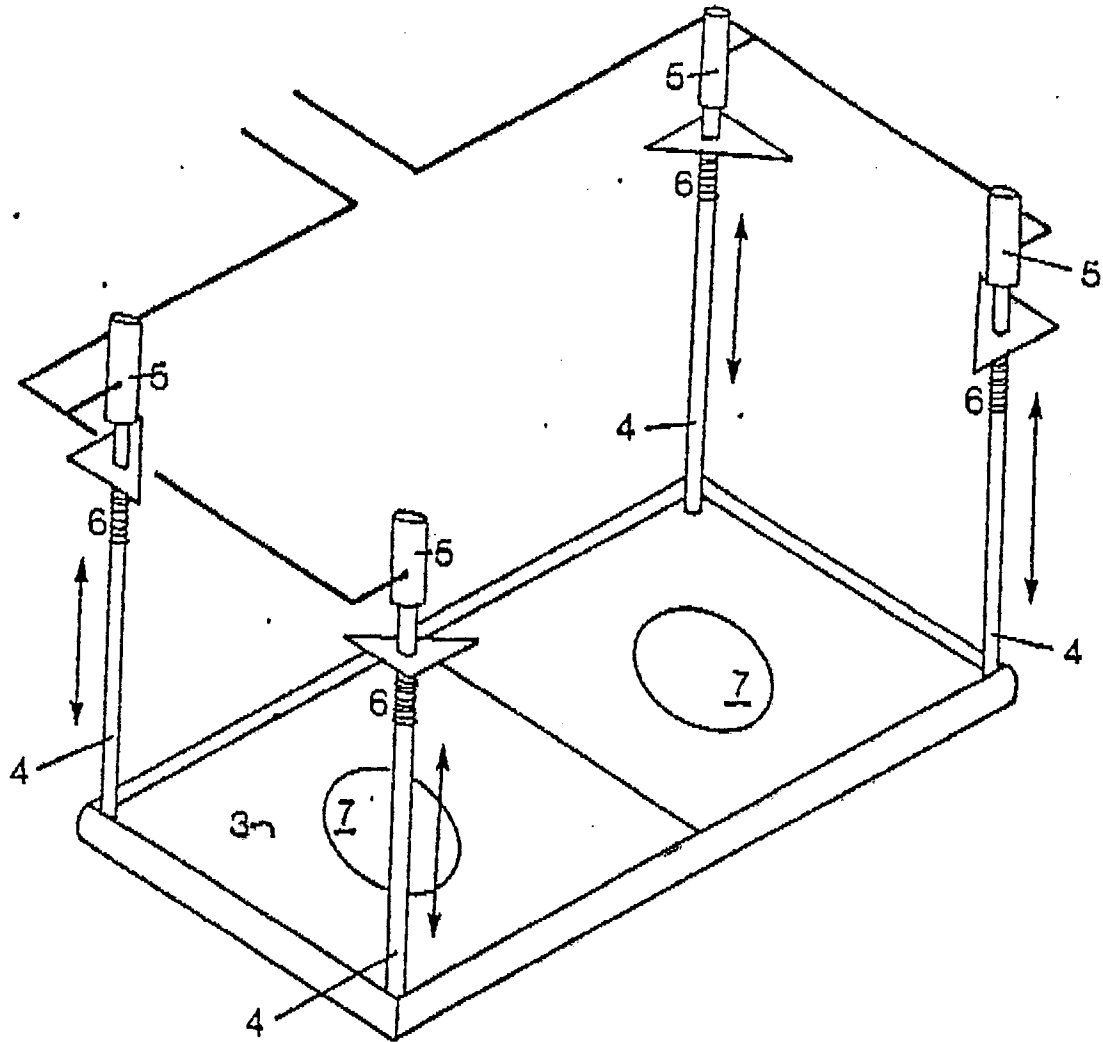


Figure (1b)

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Figure (2)

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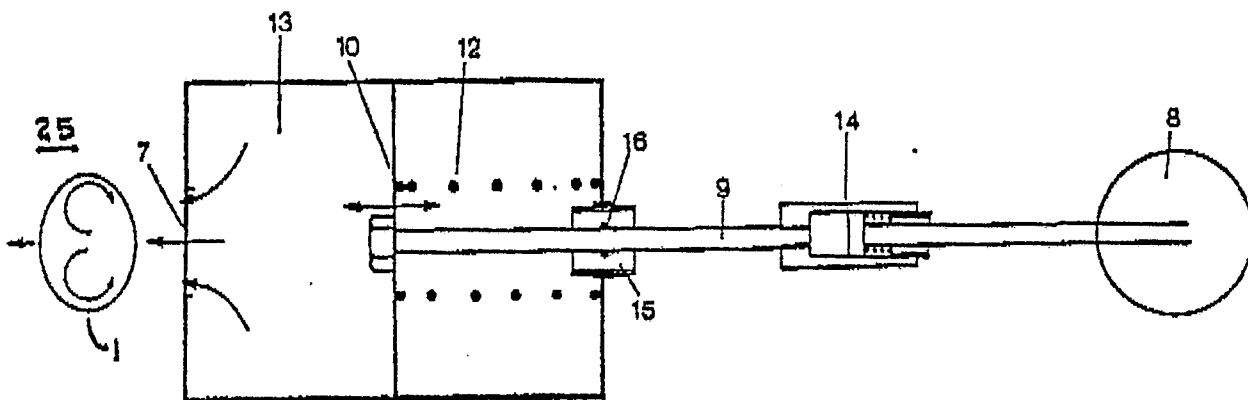


Figure (3a)

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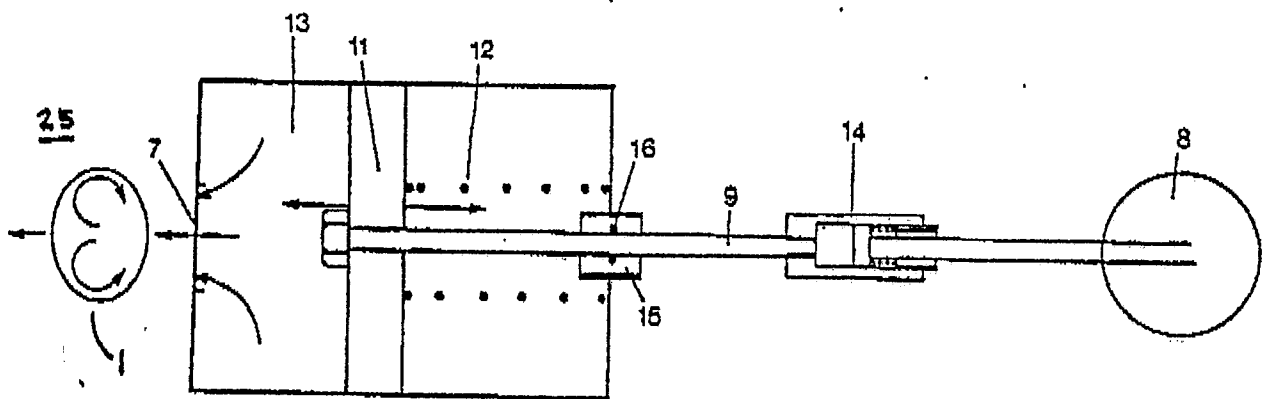


Figure (3b)

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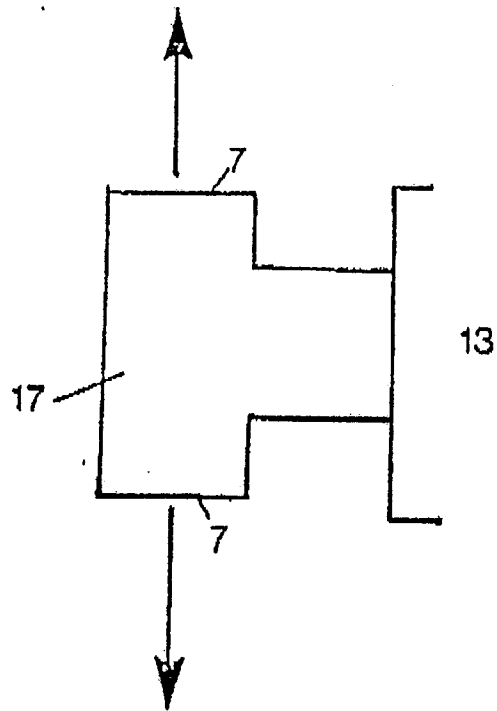


Fig. 4a

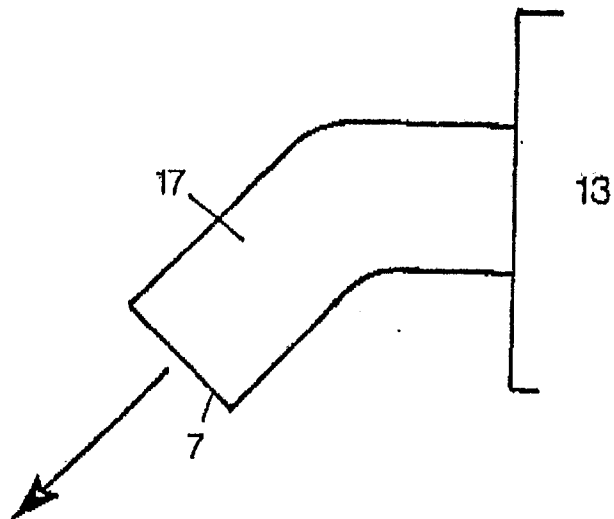


Fig. 4b

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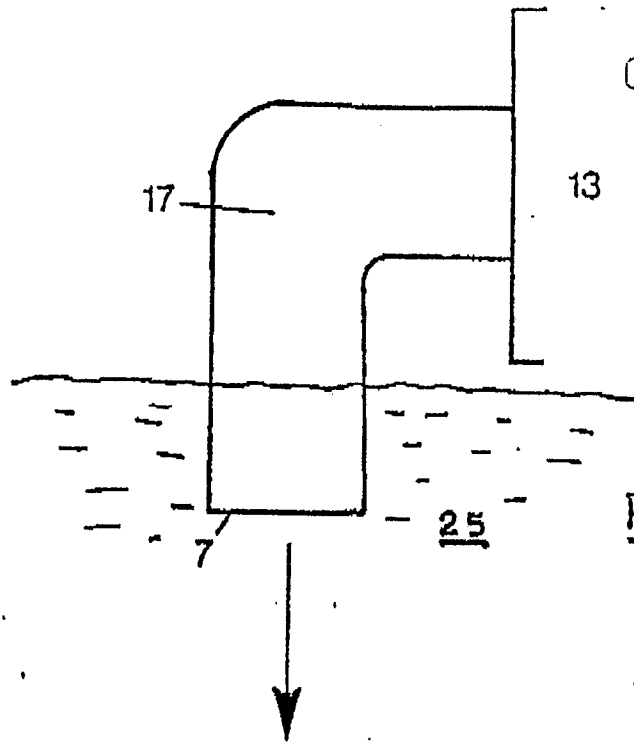


Fig. 4c

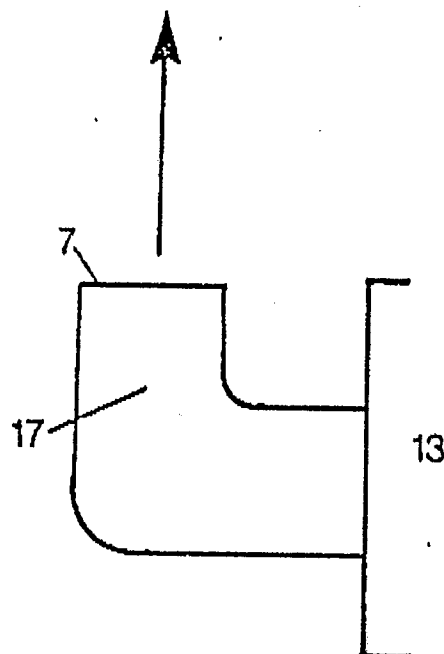


Fig. 4d

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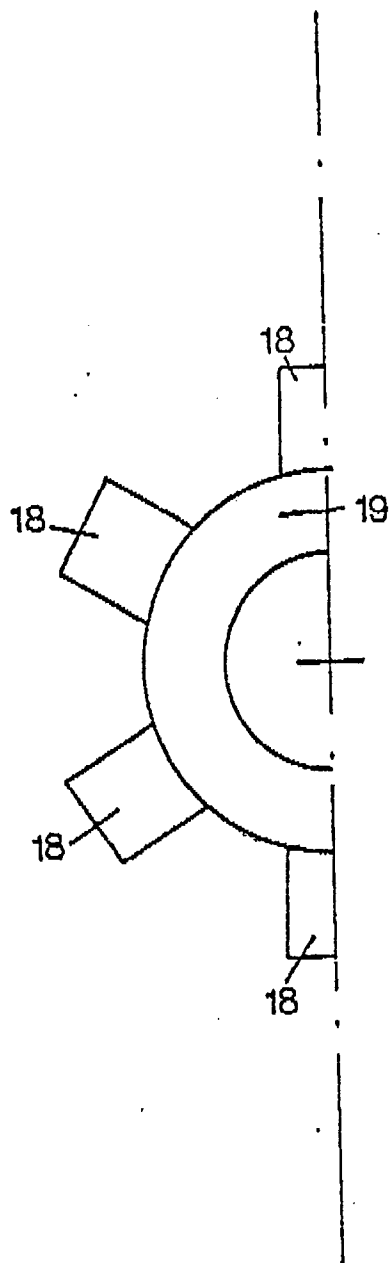


Fig. 5a

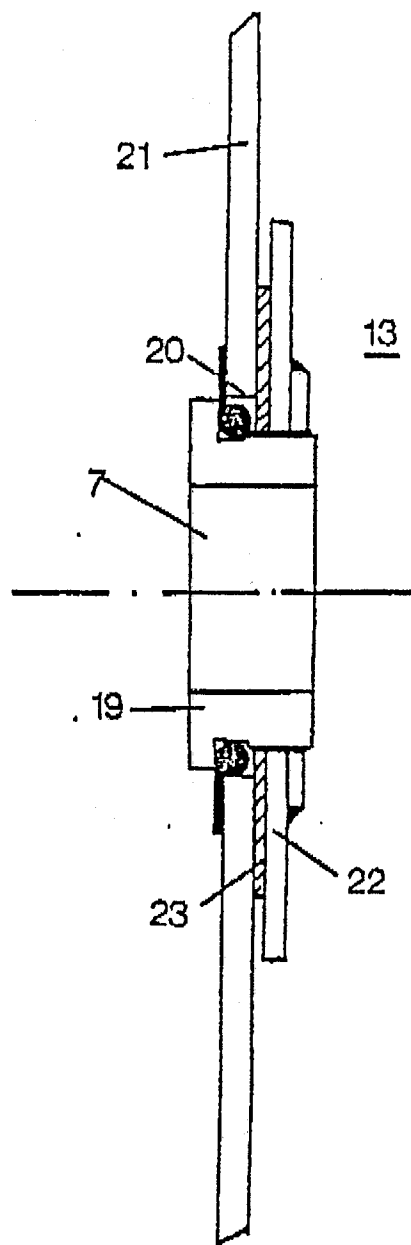


Fig. 5b

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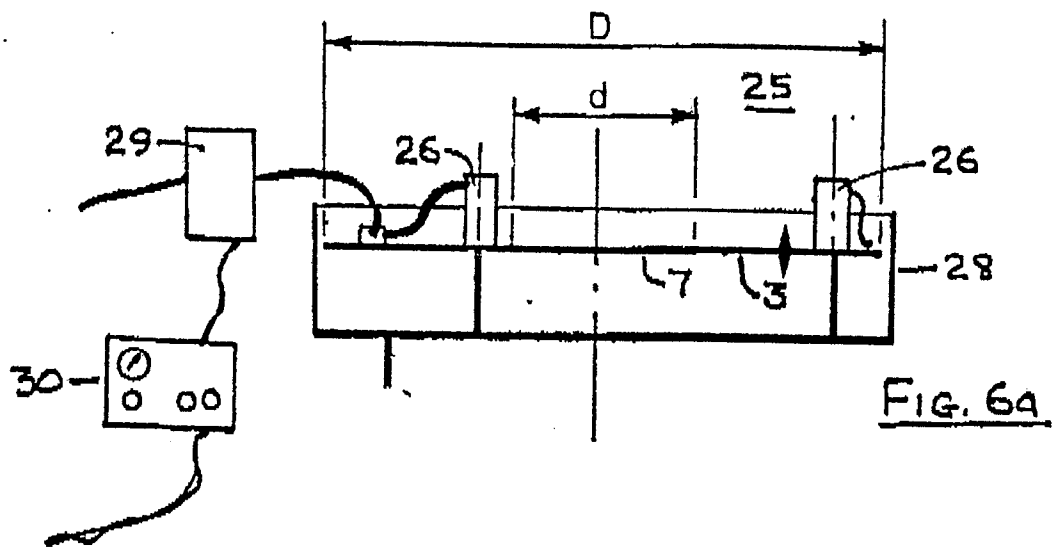


FIG. 6a

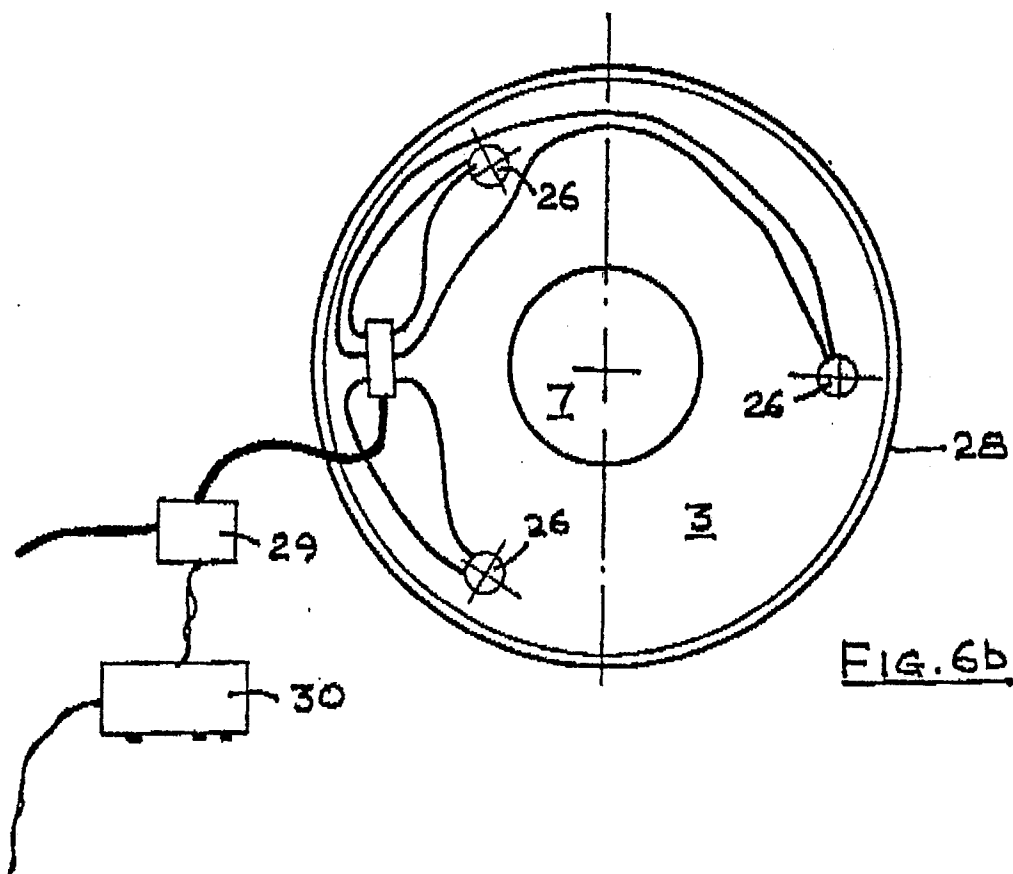


FIG. 6b

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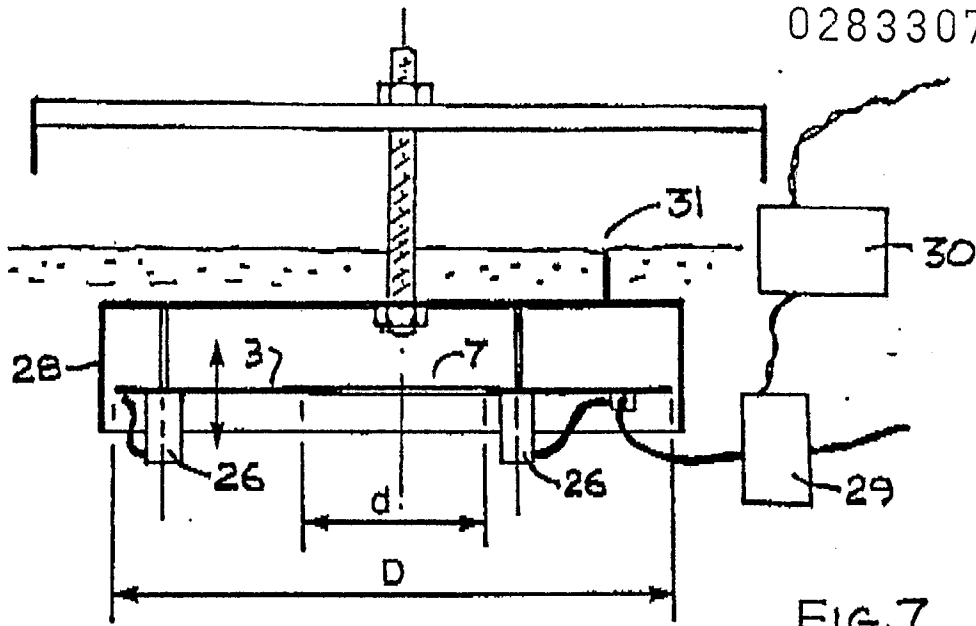


FIG. 7

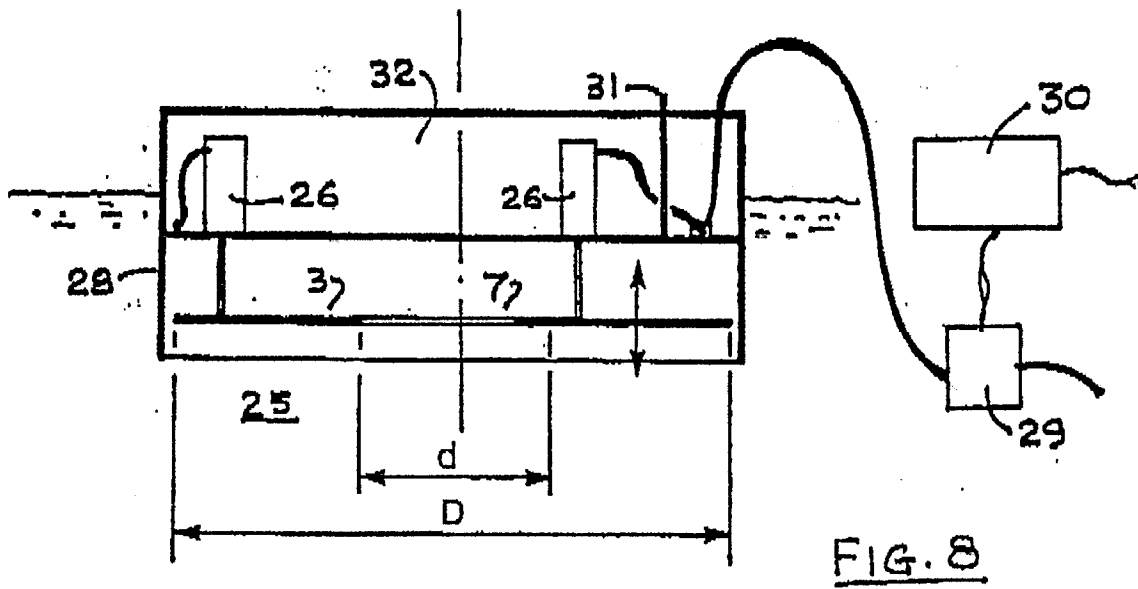


FIG. 8

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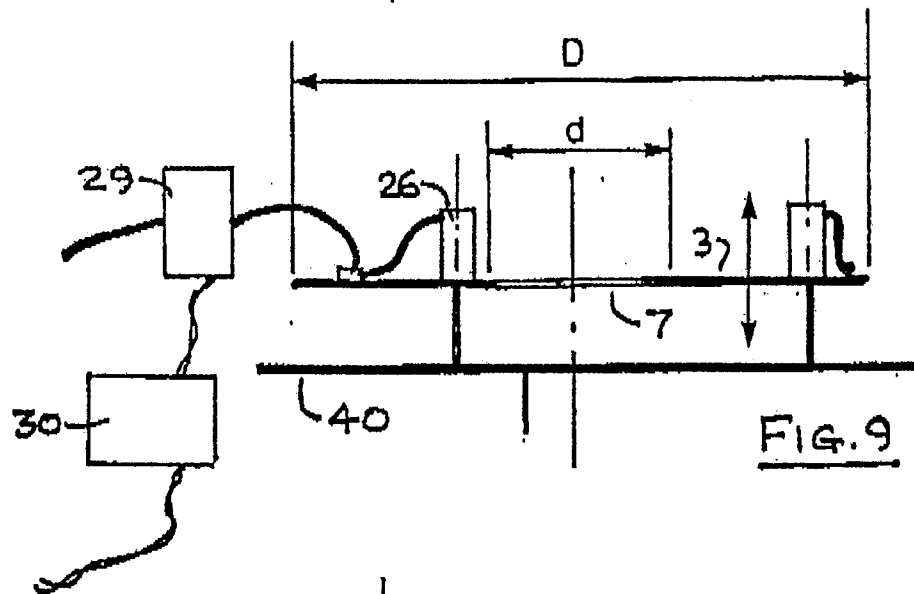


FIG. 9

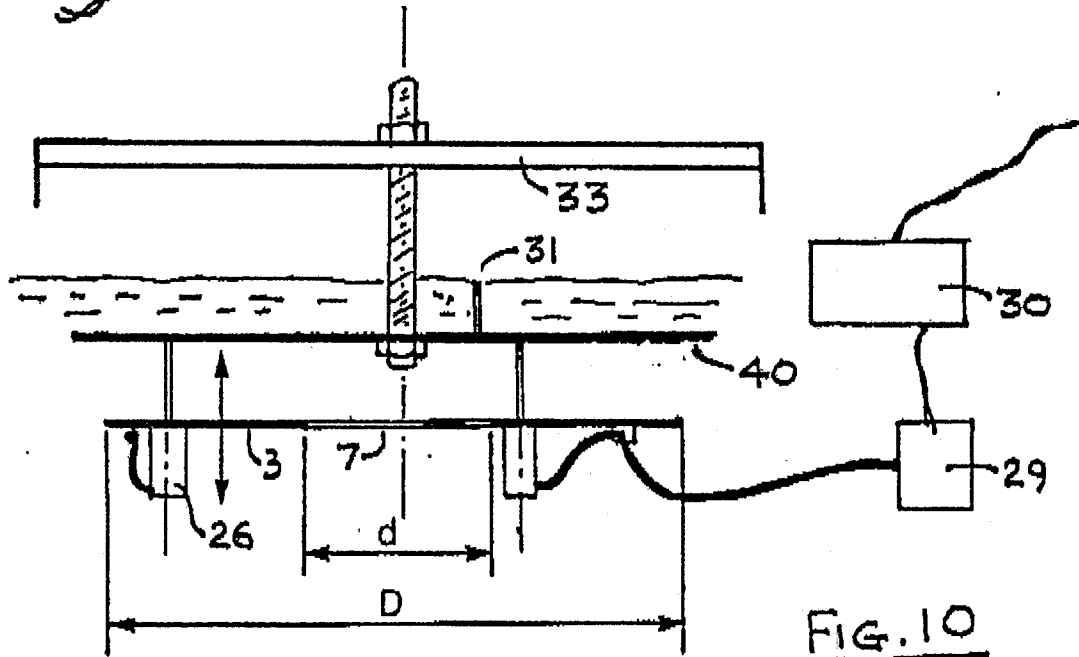
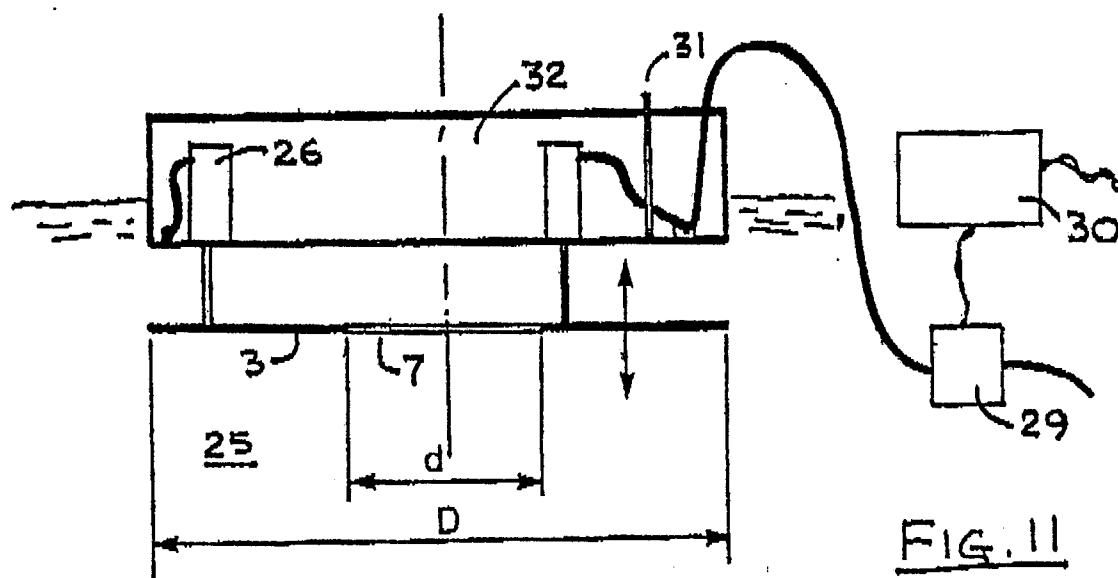
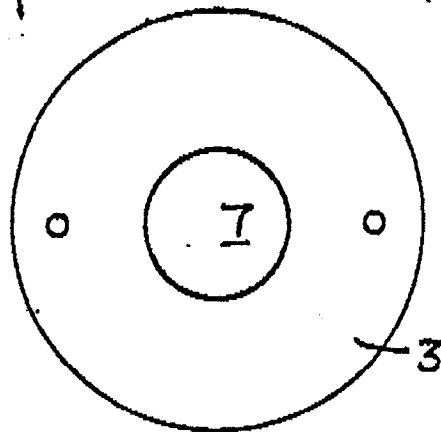
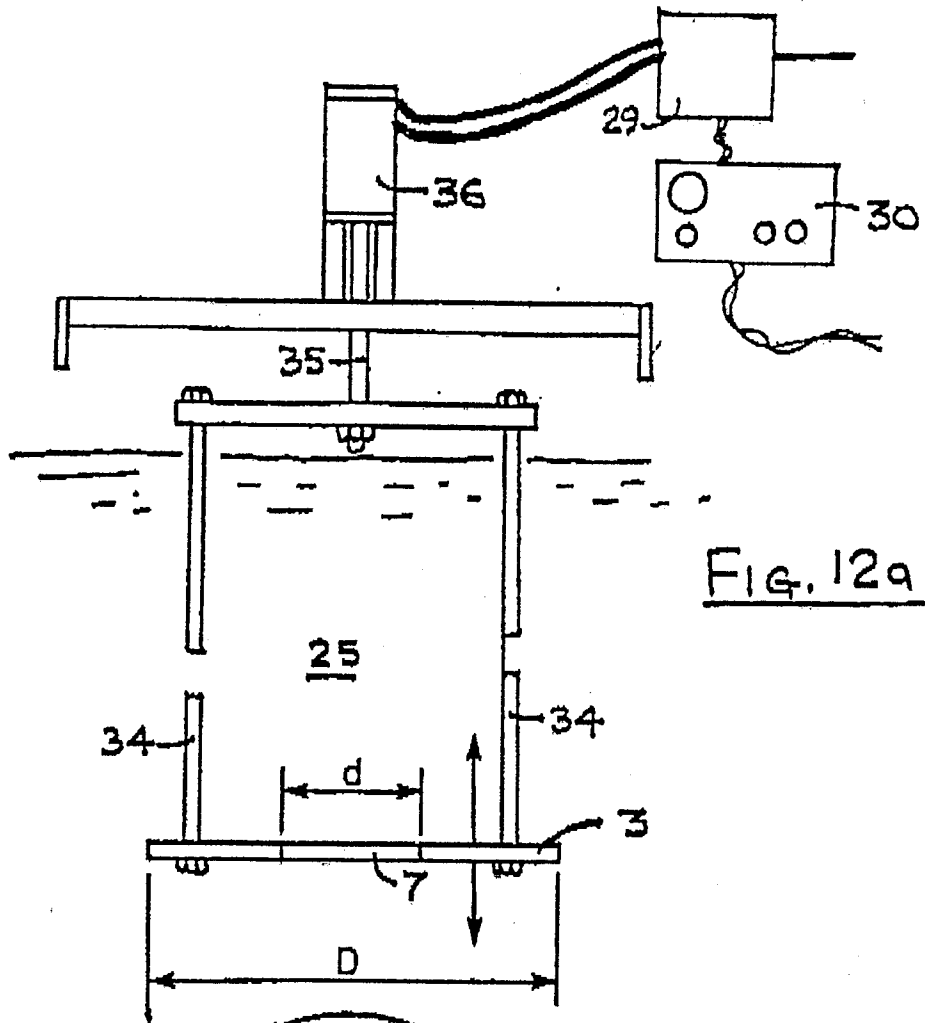


FIG. 10

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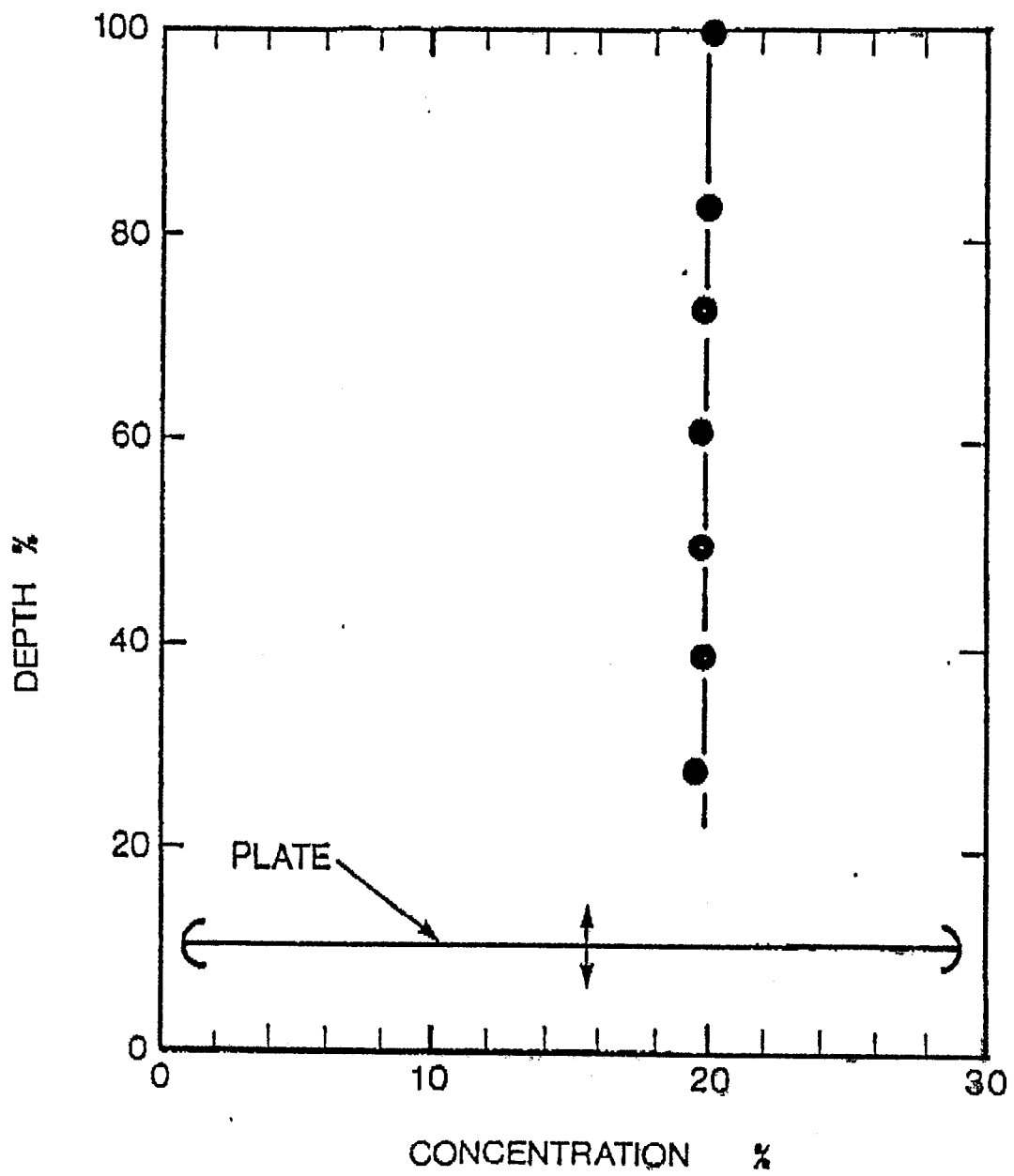


FIG. 13