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(54) **Unit of a generator of gas bubbles in a liquid**

(57) Subject of the invention is a unit generating small gas bubbles in liquid, based on the already known method of the generated bubbles being small if they are exposed, during their formation, to periodic oscillation. In the present embodiment, the aerator generating the bub-

bles is integrated in a unit with the no-moving-part oscillator. This is a previously unknown layout using the time delay of flow spin-up and spin-down to generate low frequency oscillation which were found to intensify the small bubble generation.

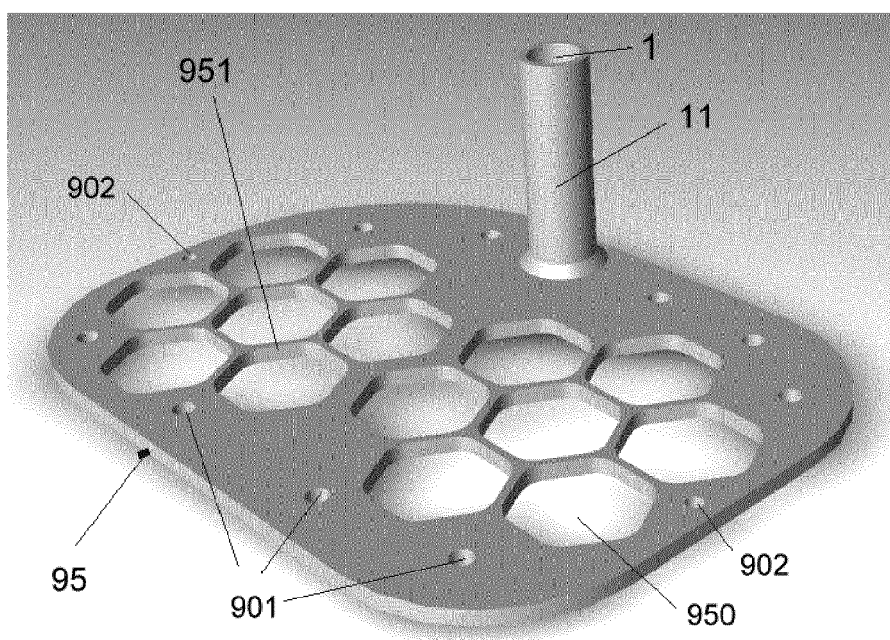


Fig. 1

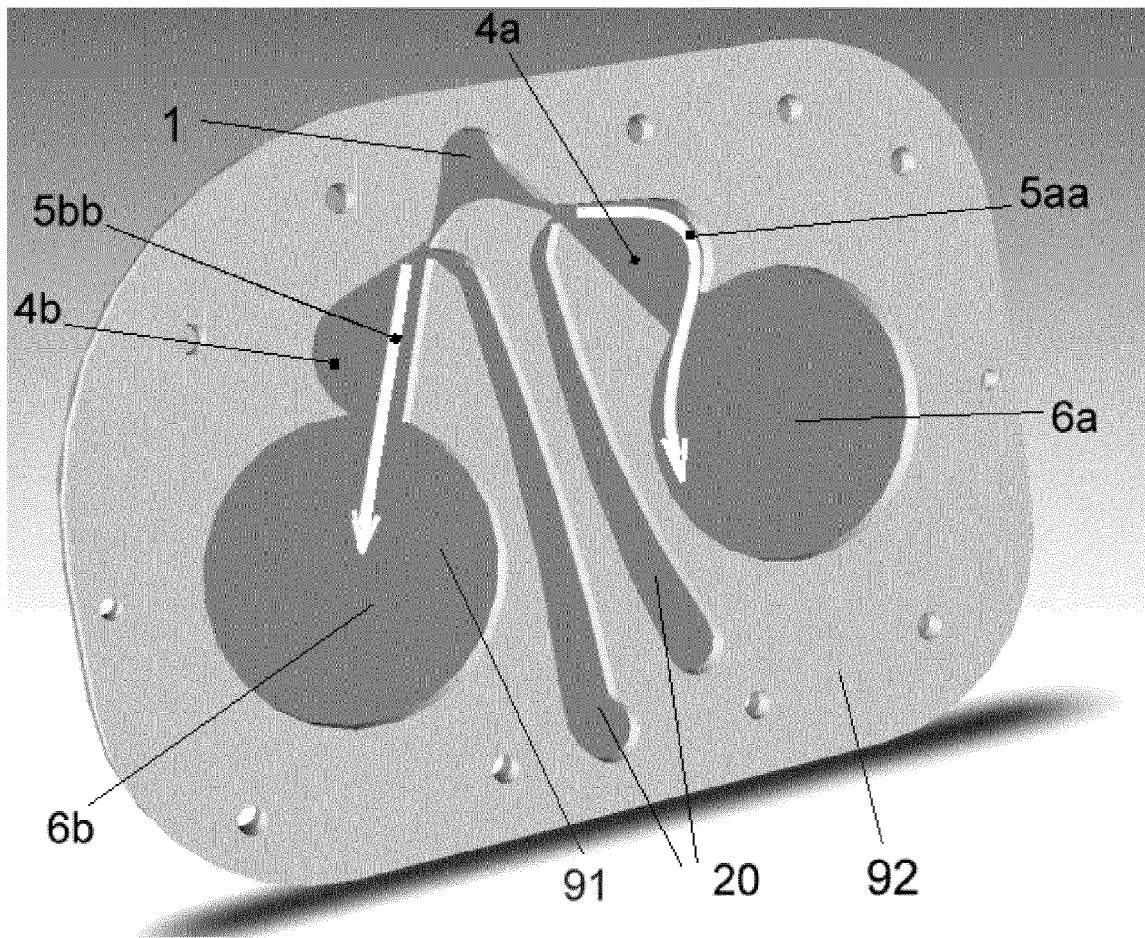


Fig. 4

Description

Technical field

[0001] The subject of this invention is a unit forming a part of a generator which produces in a liquid small bubbles of gas brought into the unit by a pipe or other cavities. Small bubbles are required in a wide range of production processes, in particular those in which the supplied gas has to diffuse across the phase interface into the liquid. An example is aeration of water to increase its oxygen content. In this as well and in majority of other cases it is desirable for the generated bubbles to have the least possible dimensions, because the gas diffusion transport increases with increasing interface area - and the total area is much larger if a given gas volume is divided into a large number of small bubbles. Moreover, the small bubbles rise more slowly towards the liquid surface and this increases the total time over which the transport from the bubbles into the liquid takes place.

[0002] In many industrial processes is demanded rather high overall transport rate from the gas into the liquid. In such cases it is expected that for achieving the high total transport rate will be used a larger number of the units as described in this invention, all operating in parallel.

[0003] Use of gas bubbles in a liquid is common in a whole range of engineering areas and in practically all is found a possible application for a method producing the bubbles extraordinarily small, as can be done in the unit according to this invention. To such areas belong in particular waste water processing, production and recycling of paper, separation of various materials by flotation, producing such organic substances as yeast and, in particular, potentially very important growing of unicellular (as well as even more complex) plants such as the well known algae.

Background art

[0004] The simplest and most often used method of generating bubbles is bringing the gas into a device known as aerator. This device is characterised by a large number of small orifices connected at one end to the common gas supply and at the other end open into the liquid. The liquid is usually inside a vessel or tank and the aerator is submerged under the liquid level. The bubbles are then formed by outflow of gas from the small orifices of the aerator. The main problem is instability of parallel bubble formation. This is a direct consequence of the basic law governing bubble behaviour. According to this law, the pressure difference between the gas inside the bubble and the surrounding liquid is inversely proportional to the curvature radius of the bubble surface (the Young-Laplace law). If the bubbles are generated simultaneously at the exits from the small parallel orifices of the aerator, and due to some chance effect one of these bubbles increases its size - and thus also increas-

ing its curvature radius - then the gas pressure inside this larger bubble will be lower than in the neighbour bubbles supplied by the gas from the same gas source. Of course, the gas then will flow, driven by the larger pressure difference, into the bubble that is already larger, at the expense of decreased or even stopped gas flow into the neighbour bubbles. They cease to grow, while the large bubble will reach an extremely large size, out of proportion to the size of the aerator orifice exits. Despite all the effort directed to making the aerator orifices as small as is allowed by the orifice manufacturing method, the growth of very large bubbles is not influenced. What is mostly generated are big bubbles.

[0005] Way and means towards suppression of this process were sought and one of the promising possibilities suggested as a solution is disclosed in the European

Patent EP2081666 (inventors: Tesař and Zimmerman). The idea is to act on the gas supplied into the aerator orifices by flow pulsation produced by a fluidic oscillator.

[0006] The fluidic oscillator to be used for the purpose was already earlier described in an article by authors

Tesař V., Hung C.-H., and Zimmerman W.: "No-Moving-Part Hybrid-Synthetic Jet Actuator", Sensors and Actuators A, Vol. 125, pp. 159-169, 2006. This oscillator, as it is also described in the Patent EP2081666, consists of a fluidic diverter amplifier having no components that are moved or deformed in the course of amplifier operation - and from a feedback loop channel. The channel connects the two control terminals of the amplifier. The gas is supplied into the supply nozzle of the amplifier and leaves it as a gas jet into a space between two mutually opposed attachment walls. The attachment of the jet to one of them is by means of the well-known Coanda phenomenon of fluid jet clinging to a solid wall. The jet is actually held deflected at the wall by the low pressure which is acting also in the control nozzle on the same side of the amplifier. Since there is the feedback loop channel connected to the control terminals, the pressure difference arises between the ends of the feedback channel. This difference generates a flow in the channel. Gas leaving the low-pressure end of the feedback channel forms a control jet that acts on the supply jet and causes its separation from the attachment wall. The jet cannot remain straight and after the separation therefore attaches to the opposite attachment wall. These changes in the control nozzles generate in the feedback loop channel alternating-direction flow. The control actions in the amplifier produce alternating output flow in the two exit terminals of the diverter oscillator. Gas flow leaves one output terminal in first half of the cycle and the other terminal in the rest half of the cycle. According to EP2081666, there is an aerator under the liquid surface connected - usually by means of a hose - to each output terminal of the oscillator.

[0007] In existing patent literature are described inventions using the effect of oscillation on the generated bubbles. Characteristic for these earlier inventions is the os-

cillator action achieved by moving or deformed mechanical components. Even though this leads to small size of generated bubbles, there are several disadvantages associated with the mechanical movements or deformations. Typically, it is necessary to lubricate the bearings holding the mechanical components, the contact or sealing surfaces, or it is possible that the deformed component breaks as a consequence of material fatigue. All these problems are removed with the fluidic oscillator. In particular, with the use of the fluidic oscillator according to EP2081666 is obtained a long life, reliability, and the absence of maintenance.

[0008] On the other hand, the solution according to the European Patent EP2081666 is also not without some disadvantages.

[0009] These disadvantages follow from the recently discovered fact that the desirable small size of generated bubbles is obtained in particular at low oscillation frequency. The low frequency is also desirable also in those situations where the bubble size is not significantly dependent of frequency. This is because the energy spent on generation of each is roughly the same so that if the oscillation cycles are repeated at a low frequency the power spent on them during a unit of time is lower. However, the fluidic oscillator described in the Patent EP2081666 is suited for high frequency oscillation. The frequency in that oscillator is determined by two factors: by the magnitude of the air (or another gas) flow rate through it, and by the length of the feedback loop channel.

[0010] This is associated with the following disadvantages:

- a) If the flow rates are small, the number of generated bubbles from a particular oscillator is small; thus the economy of bubble generation is decreased.
- b) A more important factor are the friction losses in fluids which increase in relative importance as the flow rate - and the corresponding Reynolds number values - are decreased. The friction can increase to such a degree that at very low frequency the processes inside the fluidic amplifier are damped and the amplifier loses its functional capability.
- c) At low oscillation frequencies the lengths of the feedback loop channels are excessive. In the Patent EP2081666 is shown an example of the diagram of dependence of the frequency on the loop length where the necessary length of the feedback channel was 50 metres and more. Cavities so long cannot be manufactured together in a single production operation with the cavities of the amplifier by the manufacturing methods usually used for the amplifiers, like laser cutting or photochemical processes with etching the material of the cavities. What come practically in question is to make the feedback loop channel in the form of a long hose or tube fixed by its ends to the amplifier body. The necessary lengths of the hoses or tubes are, however, extraordinarily impractical. The oscillator is then no more - as it is at high

frequencies - a compact entity but it is difficult to stow. It is necessary to make or find suitable spaces into which the long lengths of the hoses may be placed. Manufacturing of the fluidic oscillator is then more expensive due to the manual work necessary to connect the hose and the ferrules on the amplifier body. No connection of disparate entities like the hose and a solid body of the amplifier is one hundred percent reliable, the oscillator with the hose is less robust and more sensitive to various mechanical action: the connected hose may be accidentally removed in any manipulation with the oscillator.

d) Current soft materials of hoses and tubing, such as, e.g., rubber, lose their properties with time. They exhibit a lower mechanical strength. It is necessary to incorporate into the procedures some maintenance operations associated with replacement of weathered or aged hoses - or it is necessary to choose higher quality hose material, which is, of course, more expensive.

e) In very long hoses used in the role of the feedback loop channel, sometime with lengths of the order of metres and more, it is inevitable that the energy of the transported fluid flow is decreased by friction on the hose walls - especially if the hoses are not straight but have to be coiled for stowage. A considerable percentage of the transferred feedback signals become lost. It is necessary, to incorporate these losses, to select a higher working pressure of the air (or gas in general) supplied into the oscillator. This increases the operation expenses, because compressed air is a quite expensive commodity.

Disclosure of the invention

[0011] The disadvantages named above are removed by the unit of a generator of gas bubbles in a liquid connected to the inlet of the gas into the vessel containing the liquid according to this invention.

[0012] The subject of this invention is a unit of a generator of gas bubbles in a liquid connected to the inlet of the gas into the vessel containing the liquid that has the gas supply channel for the flow of the gas branched into at least two concurrent flowpaths each of which contains six components connected in series, namely a nozzle, pre-chamber, vortex chamber, central exit, distribution cavity, and a porous wall open into the vessel with the liquid where the nozzle is directed by its mouth into the pre-chamber and downstream from the nozzle is each flowpath inside the pre-chamber bifurcated into two alternative routes, namely a tangential and a radial route, both entering the vortex chamber, where the radial route is adjacent to an attachment wall directed towards the central exit while in the diverting location at the beginning of the two routes between the nozzle and the beginning of the attachment wall contains mouth of the connection channel leading between the first flowpath and the second flowpath.

[0013] According to this invention the unit of a generator of gas bubbles in a liquid connected to the supply of the gas into the vessel containing the liquid may be also characterised by the fact that both the tangential route as well as the radial route lead from the pre-chamber to the axisymmetric vortex chamber through a single common orifice and the pre-chamber has opposite to the attachment wall a antipodal wall that is inclined to it by an angle α larger than 16 angular degrees and further that between the antipodal wall and the vortex chamber there is a protruding nose.

[0014] The purpose of this arrangement is simplification of manufacturing of the unit, especially if it is made from a stack of plates with cavities made by removal of the plate material.

[0015] The unit of a generator of gas bubbles in a liquid connected to the supply of the gas into the vessel containing the liquid may also have two orifices leading into the same vortex chamber, namely one orifice for the tangential route and another orifice for the radial route the said routes being formed each of them at a different side of the splitter.

[0016] This alternative layout may cause difficulties in the manufacturing process, but if the manufacturing problems are solved then this layout has the advantage of lower energetic losses, in particular for the radial route flow, because the flow through a closed conduit leads to lower pressure loss than a flow into which may be entrained the surrounding fluid.

[0017] The unit of a generator of gas bubbles in a liquid according to this invention may have inside the vortex chamber positioned a guiding blade shaped into an arch. It was demonstrated that the presence of the guiding blade has a favourable influence on the radial flow through the vortex chamber.

[0018] The unit of a generator of gas bubbles in a liquid connected to the supply of the gas into the vessel containing the liquid according to this invention may have, if the manufacturing aspects are solved, the upper wall of the vortex chamber and/or the bottom wall of the vortex chamber the shape of a cone.

[0019] Unit of a generator of gas bubbles in a liquid according to this invention may be advantageously made as a set of plates stacked on each other, containing the top plate provided with exit holes and under it a woven metal textile the part of which under the exit holes forms the porous wall of the distribution cavities where fastened to the top plate under the metal textile is the distribution plate to which is fastened partition containing central exits, the latter connected to the main plate to which is fastened the bottom plate and with advantage the carrying pipe connected to the top plate while the pre-chamber and the vortex chamber are made in the main plate and the distribution cavities are made in the distribution plate.

[0020] Making the cavities in a body by the method of stacking the body from plates is the simplest way of manufacturing complex shaped cavities inside a solid body.

[0021] Conveniently the supporting ribs are placed be-

tween the exit holes in order to decrease the mechanical stressing of the metal textile caused by the gas pressure.

[0022] It is possible to apply for manufacturing of the unit a generator of gas bubbles in a liquid connected to the supply of the gas into the vessel containing the liquid according to this invention various materials and manufacturing techniques, some of which are mentioned in the following discussion of the examples of the unit.

[0023] The basic manufacturing problem is the rather complex shape of internal cavities.

[0024] It is advisable to make them by applying some computer controlled production methods as is cutting by laser or controlled polymerisation. As for the materials suitable for making the unit, there is a quite wide choice.

The selection criterion is resistance to corrosion and to mechanical stressing. Suitable from this point of view are stainless steels or polymer materials. A stainless steel is the choice for material removal, e.g. by laser cutting the cavities in plates, the "rapid prototyping" with computer controlled polymerisation will be the choice method for manufacturing from a monomer liquid. The "rapid prototyping" offers the advantage of making the whole unit in a single manufacturing operation - while its disadvantage is a higher cost. Very advantageous is the computer-controlled laser cutting from flat metal plates.

[0025] The unit according to this invention achieves new and higher effects than the previously known versions due to the fact that it is particularly suitable for being made in a very compact layout and with minimum spatial requirements, because it unites in a single solid body, submerged under the liquid level, the oscillator as well as two aerators immediately connected to the oscillator exits. The most important fact, however, is easy achieving of low oscillation frequency of the oscillation due to the time delays which are due to gradual spin-up of the fluid motion in the vortex chambers during each cycle - and then equally slow stopping of the rotation in the subsequent part of the cycle. The disadvantages are removed that are listed above as arising in known oscillators from the necessity to have the very long hoses for the feedback loops.

[0026] The most frequent envisaged application of the unit is producing tiny air bubbles in processed waste water, where the actual processing is done by bacteria that in present waste water processing plants die due to the lack of oxygen and cannot fulfil their task completely. With the aeration by very tiny air bubbles the life of the bacteria is longer and at the same time the smaller financial expenditure is needed for supplying the compressed air. Similar advantages for providing more gas transfer surface into the liquid are there in oxidative leaching of plutonium, photoresist removal from silicon wafers, separation of various materials by froth flotation, yeast production, sonochemical synthesis, salvaging crude oil from exhausted oil wells, and growing unicellular organisms and algae as the basis of food chain.

Description of the drawings:

[0027]

Fig. 1 - The top plate of the unit in the first of the discussed examples.

Fig. 2 - View of the first example of the unit without the top plate and without the metal textile which in the fully assembled unit is under the top plate.

Fig. 3 - View of the first example of the unit with some of the parts removed so that it is possible to see the part called partition.

Fig. 4 - View of the most important plate with cavities of the first example.

Fig. 5 - Schematic representation of the units valid for all discussed examples.

Figs. 6 and 7 - Trajectories of fluid flow in the cavities of the first example. Two illustrations show two different basic function regimes.

Fig. 8 - The most important details of the component of the first example.

Fig. 9 - Flow in the cavities of the first example obtained by computer flowfield solution.

Fig. 10 - Schematic representation of the pressure distribution along the two flowpaths of the gas passing through the unit.

Fig. 11 - A part of the alternative example differing in the splitter between the two routes leading into the vortex chamber.

Fig. 12 - Another of a part of the unit made by stereolithography.

Fig. 13 - Yet another example of the unit made by stereolithography.

Fig. 14 - An example of a part of the unit made by selective laser sintering.

Fig. 15 - An example of a part of the unit containing the guiding blade.

Fig. 16 - Computed trajectories of the gas flow in the pre-chamber as well as vortex chamber of the example with the guiding blade.

Fig. 17 - Another example of the unit with easier flow through the vortex chamber in the regime without rotation.

Fig. 18 - Another alternative example of the vortex chamber.

Fig. 19 - Yet another example of the vortex chamber in the unit according to this invention.

Examples

Example 1

[0028] The unit according to this invention as shown in Figs. 1 to 4, is an example manufactured by the plate stack method. The necessary cavities inside the unit body are manufactured by material removal separately in the plates. Operation of the unit - as is the case in all the examples of the unit discussed below - depends on

oscillatory gas flow with the oscillation generated in cavities inside a solid body. There are several methods how to make the cavities and the stack method is one of them. The cavities are made separately in each flat plate of the stack by the known methods like laser cutting or electric discharge machining. Then the finished plates are stacked and held together. They may be welded together to form a single solid body - or they may be held by screws or similar fasteners allowing disassembling the unit.

[0029] The particular version presented the first four pictures is intended for producing air bubbles in waste water, such aeration being an important step in the wastewater processing. Without significant changes this unit may be used in other cases of aeration of a liquid. The unit consists of five stainless-steel plates of equal outer shape and, in addition, there is also a thin mesh made by weaving from very thin stainless steel wires (in this particular case the wires are of 40 μm diameter). This woven steel textile layer is of the same external shape as the other plates in the stack, inside which it is clamped between the uppermost plate and the plate immediately below. The unit is in operation wholly submerged in the liquid, held from above by the carrying pipe 11. The plates forming the unit are held in a horizontal position horizontal. The internal cavity of the carrying pipe 11 serves as the supply channel 1 bringing compressed air into the unit. In the form of bubbles, the air then leaves the unit into water through the above mentioned mesh.

[0030] Mutual position of all plates in the unit is secured by two dowels inserted into the dowel holes 902 made at the same position in each plate. There are also nine screw holes 901, also at the same position in each plate. Stainless-steel screws passing through the screw holes 901 keep the stack together and secure the clamping force holding the mesh.

[0031] The top plate 95 removed from the unit is shown in Fig. 1. The carrying pipe 11 (only a short segment of which is shown in Fig. 1) is welded to the top plate 95. Apart from the nine screw holes 901 and two dowel holes 902 there are in the top plate 95 also fourteen exit holes 950 of roughly hexagonal shape. These exit holes 950 expose the metal-textile layer, which is held under the top plate 95. Some areas of this layer, located under the exit holes 950, thus form the porous walls 9a, 9b of the distribution cavities 8a,8b made in the distribution plate 94. Between the exit holes 950 there are supporting ribs 951. They support the thin metal textile layer and prevent its damage by the force action of compressed air, which is brought to the textile from below.

[0032] In the picture of the unit presented in Fig 2, both the top plate 95 and the metal textile layer are removed, which allows seeing the distribution plate 94. Also the screws and dowels are removed in Fig. 2. Apart from the holes for these fastening components, there are in the distribution plate 94 two holes, made together with other material removal in a single manufacturing operation by programmed laser cutting. These two holes are star-shaped, with blunt tips of the star. At left this hole forms

the first distribution cavity 8a and at right it forms the second distribution cavity 8b. By comparison with Fig. 1 it is apparent that the distribution cavities 8a, 8b are each under the seven exit holes 950. The air from the distribution cavities 8a, 8b thus can escape upwards through the metal textile supported by the supporting ribs 951. In addition, in the top part of Fig. 2 is seen a round hole which is a part of the supply channel 1. In the bottom part of Fig. 2 there is an arc-shaped interconnection channel 941.

[0033] Shown on the next Fig. 3 is the unit with also the distribution plate 94 removed. This makes possible to see well the partition 93. It is thinner than other plates, also made of stainless steel and with the same outer shape as the shape of other plates. Apart from the nine screw holes 901 and two dowel holes 902 there are in the partition 93 altogether five round holes. On top is again visible the hole that forms a part of the supply channel 1. On the right-hand side there is the first central exit 7a and on the opposite left-hand side there is the second central exit 7b. Then there are also the interconnection holes 931 which in the assembled unit are each under one end of the interconnection channel 941 in the distribution plate 94.

[0034] It remains only to remove the partition 93, as is shown in the following Fig. 4, and this makes possible to see well the most important plate from the stack - the main plate 92. Under this main plate 92 is only the bottom plate 91 which is not shown in a separate illustration because it does not contain anything of particular interest: its outer shape is the same as that of other plates and there are only nine screw holes 901 and two dowel holes 902.

[0035] In the top part of Fig. 4 is in the main plate 92 a hole which is a part of the supply channel 1. Two concurrent flowpaths are branching from it, one at left and the other on the right-hand side. The right-hand side air flow path leads through the first pre-chamber 4a into the first vortex chamber 6a - while, almost symmetrically, on the left-hand side there is connected to the supply channel 1 the second pre-chamber 4b and the second vortex chamber 6b. By comparison with Fig. 3 it is apparent that air may leave the first vortex chamber 6a through the first central exit 7a made in the partition 93 and, on the other side, air may leave the second vortex chamber 6b through the second central exit 7b in the partition 93. To the inlet parts of the pre-chambers 4a, 4b leads the connection channel 20 which in the main plate 92 consist of two parts which both end, at the bottom of Fig. 4, in those locations where the partition 93 (as seen in Fig. 3) has its interconnection holes 931. These holes make possible - together with the interconnection channel 941 in the distribution plate 94 - union of both parts of the connection channel 20 into a single continuous channel. This connection through other plates is useful because it evades formation in the plates during their manufacturing of "islands" - the unsupported parts of the original plate that fall out in the material removal process and would ne-

cessitate expensive repositioning and fixing, a manual operation.

[0036] The gas flow is divided in pre-chambers 4a, 4b into two alternative flow routes, the tangential route 5a and radial route 5b. In Fig. 4 there are in the two flowpaths 2a, 2b two different flow conditions. In the first pre-chamber 4a the gas follows the first tangential route 5aa while in the second pre-chamber 4b the gas takes the second radial route.

[0037] For description and explanation of the processes that take place inside the unit it is useful to note the schematic representation of the air flows in the following Fig. 5. In principle this is a diagram of topological structure which is the same in all cases of the unit according to this invention. The vertical straight lines indicate some important locations. At the left-hand side of the picture Fig. 5 there is the supply channel 1 where gas (air) enters the unit. The illustration is oriented so that the gas (air) passes through the schematic representation from left to right. Represented schematically at the right-hand side are thus the two location where the gas leaves the unit and enters the vessel containing the liquid in which the bubbles are produced. This departure of the gas takes place through the first porous wall 9a of the first distribution cavity 8a on one side - and through the second porous wall 9b of the second distribution cavity 8b on the other side. So that they can mutually exchange their role during each operating cycle, the porous walls 9a, 9b are placed at the ends of two concurrent paths, the first flowpath 2a and second flowpath 2b into which the supply channel 1 bifurcates. In Fig. 5 the first flowpath 2a is in the top part of the picture while in the bottom half is the second flowpath 2b. Both flowpath pass through nozzles. The first flowpath 2a passes through the first nozzle 3a and the second flowpath 2b through the second nozzle 3b. Air issued through both nozzles 3a, 3b into the respective pre-chambers: the first nozzle 3a into the first pre-chamber 4a and the second nozzle 3b into the second pre-chamber 4b. Immediately downstream from the pre-chambers 4a, 4b there are diverting locations 10a, 10b where secondary branching takes place. The two alternative routes downstream from this diverting locations 10a, 10b have different purposes and essentially should not be active simultaneously. Shown in Fig. 5 is a particular phase of the oscillation in which the gas passing through the first flowpath 2a follows after leaving the first nozzle 3a the first tangential route 5aa through the pre-chamber 4a and into the first vortex chamber 6a. It does not use the available first radial route 5ba. In the second flowpath 2b the reverse is true at this phase. The gas leaving the second nozzle 3b attaches to the second attachment wall 14a which leads it through the second radial route 5bb into the second vortex chamber 6b. Tangential routes 5aa, 5ab and radial routes 5ba, 5bb meet again in the vortex chambers 6a, 6b. For example, the gas following the first flowpath 2a leaves the first vortex chamber 6a through the first central exit 7a into the directly to it connected first distribution cavity 8a and

through the first porous wall 8a into the vessel containing the liquid. The attachment of the gas to the second attachment wall 14b shown in the second flowpath 2b - and, on the other hand, the absence of such attachment to the first attachment wall 14a - is controlled by alternating flow in the connection channel 20 and its flow out from the second mouth 13b. Decisive role is played by pressure distribution in the cavities of the unit.

[0038] On the two following illustrations, Fig. 6 and Fig. 7 are shown in identical perspective views the results of numerical flowfield computations showing trajectories of gas particles in the pre-chambers 4a, 4b and vortex chambers 6a, 6b. The geometry of the chambers corresponds exactly to that shown in Fig. 4. The computations were made for everywhere the same depth of the cavities, equal to the thickness 4 mm of the main plate 92 and for the 70 mm diameter of the vortex chambers. The width of the nozzle 3a, 3b in this case was 2.56 mm. In the situation shown in Fig. 6 the gas, leaving the first nozzle 3a follows the tangential route 5a while in Fig. 7 the gas follows the radial route. In the original presentation of the computation results, the gas trajectories were colour coded so that the local colour corresponded to the local pressure according to the scale at left of the pictures. In the conversion into the grayscale this information is not easily recognised, nevertheless the most important are the pressure values in the two mouths 13a, 13b, shown in these illustrations. In both cases, the computations were performed for the same value

$$\Delta P_S = 9\,000\text{ Pa}$$

of the pressure in the supply channel 1 relative to the atmosphere which in the tests were outside of the porous walls 9a, 9b. In the case presented in Fig. 6 air enters into the first vortex chamber 6a by the tangential route 5a. It is directed by the nose 46 into the tangential direction and the moment of momentum thus gained generates in the first vortex chamber 6a intensive gas rotation. The flow towards the first central exit 7a is difficult. It may be noted in Fig. 6 that this situation requires additional flow from the first mouth 13a (the corresponding trajectory is recognisable in Fig. 6) joining the flow from the first nozzle 3a and actually deflecting it from its original direction of flow from the first nozzle 3a.

[0039] If, however, the gas leaving the second nozzle 3b attaches - as shown in Fig. 7 - to the second attachment wall 14b, this wall direct it without rotation towards the second central exit 7b. The computed results actually show somewhat more complex situation - it is not easy for the gas to change its direction of flow by 90 degrees to enter the second central exit 7b. Nevertheless, even with this complication the pressure in the second mouth 13b is low and in fact the difference relative to the atmosphere is negative. This is possible due to the fact that a large part of the gas energy is converted into kinetic en-

ergy.

[0040] In the following Fig. 8 are presented parts of the first flowpath 2a consisting of the first nozzle 3a, the first pre-chamber 4a as well as the first vortex chamber 6a. The illustration shows some most important aspects of the planar geometry, which were found by computations with alternative geometric features. It is shown here, that if the first diverting location 10a into the first tangential route 5a and the first radial route 5b is to be as requested in the first pre-chamber 4a, then it is necessary to select a large angle α between the first attachment wall 14a and the first antipodal wall 15a. As is known from the behaviour of diffusers, if the divergence angle between walls is smaller than $\alpha = 16$ deg, than the flow leaving the first nozzle 3a can follow both walls simultaneously. The successful behaviour as shown above in Figs. 6 and 7 was achieved with the angle twice as high than this generally accepted limit: the angle there is $\alpha = 32$ deg.

[0041] The next important fact is the necessity of the first attachment wall 14a oriented so that the extension 214 of its end is directed exactly into the centre of the first vortex chamber 6a. Also of importance is shaping of the nose 46 and a proper width of the first orifice 146a, which in the case of Figs. 6 and 7 was equal to five widths of the exit from the first nozzle 3a. For proper directing of the first radial route 5b is also important to form the shallow recession 206 in the wall of the first vortex chamber 6a.

[0042] In the following Fig. 9 is demonstrated the asymmetry of the flowfield in the cavities arising despite the fact that their shape is symmetric relative to the symmetry axis 100. The picture presents computed flow in the cavities of the main plate 92 in both flowpaths 2a, 2b at the extreme situation arising once in each oscillation cycle. In a manner similar to the previous illustrations, also here the computed trajectories of gas are coloured by the local pressure according to the scale at the left-hand side of the picture. Unfortunately, the monochromatic greyscale representation makes the pressure distribution less apparent. Both flowpaths 2a, 2b are connected to the same supply channel 1 so that the driving pressure is the same driving pressure

$$\Delta P_S = 9\,000\text{ Pa}$$

relative to the atmosphere.

[0043] The following Fig. 10 shows schematically the pressure conditions along the two flowpaths 2a, 2b. In the horizontal direction are indicated individual locations while on the vertical axis is plotted the pressure difference ΔP relative to the atmosphere. The situation represented corresponds to the case in Fig. 9: full rotation in the first vortex chamber 6a and the easy, essentially non-rotational flow in the second flowpath 2b. Different pressure values in the two flowpaths 2a, 2b in the same locations

are due to two factors. The first one is the intensity of the gas flow. The second is the effect of the large pressure drop on the first vortex chamber 6a with the rotation in it. Even though both nozzles 3a, 3b are geometrically the same, due to the easy character the flow rate in the second flowpath 2b is much larger - and, consequently, the pressure drop on the second nozzle 3b is much larger. On the other hand, due to the large pressure drop in the first vortex chamber 6a the flow rate through the first nozzle 3a is much smaller. In both flowpaths 2a, 2b a small pressure increase takes place in the upstream part of both pre-chambers 4a, 4b. This is an effect of pressure recovery in the slightly decelerating flow downstream from the exit from the nozzles 3a, 3b.

[0044] The atmospheric pressure level is marked by "0" at the right-hand side of the picture Fig. 9. While in the first mouth 13a of the connection channel 20 the pressure difference relative to the atmosphere is

$$\Delta P_a = 7\,509\text{ Pa}$$

- in the second mouth 13b the pressure difference is negative (cf. Fig. 10)

$$\Delta P_b = -1\,790\text{ Pa}$$

[0045] The total pressure difference between the two ends of the connection channel 20 is

$$\Delta P_J = \Delta P_a - \Delta P_b = 9\,300\text{ Pa}$$

[0046] It is this difference that causes the flow in the connection channel 20. An important fact is the difference ΔP_J is actually larger than the supplied ΔP_S . This is a welcome factor, increasing the intensity of the flow rate in the connecting channel 20.

[0047] Despite the fact that the geometry of the two flowpaths 2a, 2b is completely symmetric, the flow in them are asymmetric. The different conditions in the vortex chambers 6a, 6b are the usual situation. Different direction of the entrance flows into the vortex chambers 6a, 6b generated different pressure conditions and these lead to air flow in the connection channel 20. In the situation shown in Figs. 9 and 10 the flow in the connection channel 20 will be directed from its first mouth 13a, with higher pressure, to the second mouth 13b, where in this flow configuration the pressure is lower. This stops in the first pre-chamber the deflection effect that was seen in Fig. 6. The air flow leaving the first nozzle 3a stops following the tangential route 5a and sooner or later attaches to the first attachment wall 14a. The entrance flow into the first vortex chamber 6a will cease to be tangential. At the other end of the connection channel 20 the outflow from the second mouth 13b will cause the flow deflection

away from the second attachment wall 14b. The flow into the second vortex chamber 6b will cease to be radial. The first flowpath 2a and the second flowpath 2b will exchange their respective roles. This, however, does not take place immediately. The vortical motion in the first vortex chamber 6a will tend to keep its moment of momentum. On the other hand, spinning up the rotation in the second vortex chamber 6b also takes some time. The exchange of the radial route 5b and the tangential route 5a will be not instantaneous but will proceed with a time delay - despite the relative shortness of the connection channel 20. When the exchange finally takes place, the conditions will be a mirror image relative to the symmetry axis 100. The air will rotate in the second vortex chamber 6a and will find an easy way out from the first vortex chamber 6b. This stops the previous flow in the connection channel 20 and then reverses the flow in it. As a consequence of the flow reversal, the roles of the vortex chambers 6a, 6b will exchange again - coming, after a certain delay, to the initial regime. The process then can start another cycle. Each time the air rotates in the vortex chamber 6a, 6b of a particular flowpath 2a, 2b the air flow through the respective porous wall 9a, 9b decreases. The consequent flow and pressure pulsation influence the formation of the air bubbles in the exits from the pores of the porous wall 9a, 9b. In contrast to the known bubble generator disclosed in EP2081666 there are no feedback tubes of the order of metres and the unit according to the present invention is thus very compact.

Example 2

[0048] In the next Fig. 11 is shown an alternative layout of the pre-chamber 4a, 4b. The picture shows the first flowpath 2a and a part of the second flowpath 2b, which is of similar layout (it is a mirror image with respect to the symmetry axis 100, Fig. 9). The geometry of cavities is very similar to the example presented in Fig. 4. As there, the unit is a planar layout made from a stack of plates and what is shown in Fig. 11 is the main plate 92, made in a constant-thickness plate with laser-cut cavities. The layout is very similar to Fig. 4. There is the supply channel 1 at left bifurcating into two flowpaths 2a, 2b - of the latter is drawn in Fig. 11 only a part. The first flowpath 2a leads through the first nozzle 3a and the second flowpath 2b leads through the second nozzle 3b. Nozzles 3a, 3b have their exits open into the pre-chambers 4a, 4b. One of the pre-chamber walls is the attachment wall 14a, 14b where there are the secondary bifurcations into the radial route 5b and the tangential route 5a, both leading into its vortex chamber 6a, 6b. The radial route 5b in the first flowpath 2a is a direct continuation of the first attachment wall 14a of the first pre-chamber 4a and like in the layout shown in Fig. 4 the attachment of the air jet issuing from the first nozzle 3a is facilitated by the first nozzle 3a exit direction coinciding with the direction of the first attachment wall 14a. The basic difference between the layouts in Fig. 4 and Fig. 11 is there is only one orifice between the first

pre-chamber 4a and the first vortex chamber 6a in Fig. 4 while here in Fig. 11 there are two such orifices: the first orifice 146aa and the second orifice 146ba. In other words, the tangential route 5a has its separate orifice for entry into the first vortex chamber 6a. If there should be a rotation in the first vortex chamber 6a, the gas jet leaving the first nozzle 3a is to be directed into the tangential route 5a - and this means, equally as in the configuration from Fig. 4, that this jet must be separated from the first attachment wall 14a. Here in Fig. 11 the sense of the rotation generated in the first vortex chamber 6a after this separation is opposite to the rotation sense in the case of Fig. 4. The tangential route 5a is separated from the radial route 5b by the splitter 50. The straight flow through the orifice for the tangential route 5a is associated with lower hydraulic losses than in the case with the turning of the flow direction in Fig. 4. In the present case, however, the higher losses are actually welcome in the regime with air rotation in the vortex chamber 6a, 6b since it is desirable to have high pressure in the mouth 13a, 13b. Also, there is yet another advantage of the layout with the nose 64 and absence of the splitter 50: in manufacturing by the method of stacked plates the absence of the splitter 50 means there are no "islands" - those parts that fall out from the machined plate, which it is later necessary to put back and fix them in their proper position - a manual manufacturing operation which increases the cost of the unit.

Example 3

[0049] Recently introduced manufacturing methods, know collectively as "rapid prototyping" or also "three-dimensional printing", offer an alternative to the manufacturing by the above described method of material removal from flat plates that are then stacked. As opposed to the material removal, these alternative methods are based on three-dimensional computer-controlled addition of the material that forms cavity walls. A typical case is, e.g., the stereolithography in which the walls are grown from a monomer liquid that solidifies - polymerises - upon laser light activation. Another possibility is selective laser sintering in which the body of the unit is formed from powder added in thin layers to the wall locations after which the powder particles are fixed by heating them, by laser, up to the partial melting temperature.

[0050] In this third example of the bubble generating unit, presented on Fig. 12, is applied the stereolithography method. The advantage gained is more freedom in the choice of shapes of the internal cavities. Otherwise the configuration corresponds exactly to the schematic representation shown in Fig. 5. The particular problem solved by this manufacturing approach is achieving very low pressure drop across the vortex chamber 6a, 6b if the gas enters it by the radial route 5ba, 5bb. As demonstrated by the computational results presented in Figs. 7, and 9, fluid inertia makes it difficult for the radial inflow into the vortex chamber 6a, 6b upon reaching its central

exit 7a, 7b to change suddenly its flow direction by 90°. This complicates the exit from the vortex chambers 6a, 6b and increases the pressure drop across the second flowpath 2b. The freedom offered by the stereolithography is used in this example to shape the vortex chambers 6a, 6b so that the requested change in the flow direction is by an angle less than by 90°.

[0051] Figure 12 shows a part of the first flowpath 2a involving the first pre-chamber 4a and the first vortex chamber 6a. The cavities are shown in imagined meridional-plane section through the body of the unit. It is immediately apparent that - instead of the flat disk geometry in the previous examples Fig. 4 and Fig. 11 - here the first vortex chamber 6a is of conical shape, decreasing in diameter towards the apex of the cone. In the regimes without rotation in the first vortex chamber 6a the necessary turning angle for entry into the first central exit 7a is only 45° rather than the full 90°. Such a flow is easier, i.e. producing a lower hydraulic loss, which leads to a higher desirable pressure drop ΔP_j that drives the flow in the connection channel 20.

[0052] Of course, the manufacturing methods known as "rapid prototyping" need not be generally accessible. They may also be costly and their special requirements on the character of the material easily polymerised from a liquid may be not compatible with the mechanical requirements of the body of the unit. After all, at present the methods are really used just to produce a prototype verifying the geometrical spatial conditions. In the cases where the "rapid prototyping" methods are not suitable, the complex internal cavities of the unit may be made by the classical method of "lost wax" casting.

Example 4

[0053] In this next example, the freedom offered by the stereolithographic manufacture is used even more. Again, the overall configuration of the unit corresponds to the schematic representation in Fig. 5 and the part that is shown in Fig. 13 shows a section through the body of the unit involving the first pre-chamber 4a and the first vortex chamber 6a. The difference is in the shape of the first central exit 7a. It is here not coaxial with the vortex chamber axis 101 as was the case in Fig. 12 but it is here inclined so that its axis is in line with the first radial route 5ba flow. In the regime of gas flow following the first tangential route 5aa, the nose 46 directs the gas to enter the first vortex chamber 6a tangentially, as is shown by the gas trajectory with arrows. The conditions with the rotation do not differ very much from the conditions inside the cylindrical flat disk geometry in the previous examples Fig. 4 and Fig. 9. The centrifugal action makes the rotating flow difficult - and the inclined first central exit 7a makes the pressure drop even higher. On the other hand, the straight flow following the first radial route 5ba causes much lower overall pressure drop.

Example 5

[0054] The manufacturing method of selective laser sintering from powder makes possible making the manufactured product not only with solid walls, but also in a selected part of the manufactured object to make the cavity walls with tiny pores. In the example presented in Fig. 14, in a section by a meridian plane of the first vortex chamber 6a this is used for producing in a unit body simultaneously with making the solid walls also the porous walls 9a, 9b of the distribution cavity 8a, 8b, needed for generation of the gas bubbles. In Fig. 14 the first porous wall 9a is shown arched inwards into the first distribution cavity 8a. This allows making the first porous wall 9a thinner and easier for the air to pass through it without unduly stressing the sintered first porous wall 9a in tension by the force action of the compressed air. The dome-shaped first porous wall 9a is stressed by the acting pressure difference in compression, which it can better withstand.

Example 6

[0055] Easier the entry from the vortex chamber 6a, 6b into the central exit 7a, 7b by the air in the regime with the flow following the radial route 5ba, 5bb may be achieved by alternative shapes of the cavities not necessarily requesting unusual manufacturing methods. The example presented in Fig. 15 achieves the desirable effect by the presence of the guiding blade 16 positioned inside the vortex chamber 6a, 6b not far from the central exit 7a, 7b. The shape of the guiding blade 16 is derived from the shape of the air trajectories in the particular location inside the vortex chamber 6a, 6b in the regime with air rotation as shown in Fig. 6. The guiding blade 16 is very thin so that it does not in that regime produce a significantly large wake downstream from it. Thus its presence plays practically no role in the rotational regime. On the other hand, it becomes important in the regime with the air flow following the radial route 5ba, 5bb. In that regime the guiding blade 16 prevents the air flow from reaching the vortex chamber 6a, 6b wall opposite to the radial entrance, as it is seen in Figs. 7 or 9. The air is obviously forced by the blade 16 to enter the central exit 7a, 7b. This is proved by computations the result of which are the air flow trajectories shown in Fig. 16. Even though the view in this picture is a perspective view from another position than in Fig. 7 (the view angle was chosen to make more apparent the guiding blade 16), it is essentially the same regime as in Fig. 7. The trajectories in Fig. 16 show how the air has no other choice but to enter the central exit 7a, 7b - which leads to lower pressure drop across the vortex chamber 6a, 6b, as demonstrated by the computed pressure difference value included into Fig. 16:

$$\Delta P_b = -2\,690\text{ Pa}$$

- significantly lower than $\Delta P_b = -1\,790\text{ Pa}$ obtained under otherwise the same conditions without the guiding blade 16 in Fig. 7.

Example 7

[0056] Another possibility how to force the gas to change its flow direction in the centre of the first vortex chamber 6a and induce it to enter the first central exit 7a is shown in Fig. 17. In place of a single first pre-chamber 4a considered in all alternatives discussed above, there are here many pre-chambers distributed evenly on the perimeter of the first vortex chamber 6a so that first radial routes 5ba leaving these pre-chambers collide. There is, in Fig. 17, the first perimeter pre-chamber 4a1 on top at left, the second perimeter pre-chamber 4a2 on the left side below, the third perimeter pre-chamber 4a3 at right on top, and finally the fourth perimeter pre-chamber 4a4 bottom right. All of them are the same so that the stagnation point of their collision is exactly in the centre of the first vortex chamber 6a. The air flow stops in this point or slows down in its vicinity and thus the pressure rises there (by conversion from the kinetic energy). The problem with turning the flow direction of a fast flow disappears completely, air is driven through the first central exit 7a.

Example 8

[0057] In the next example Fig. 18 presents the layout of the first vortex chamber 6a in principle similar to the previous example in Fig. 17 where, however, the four perimeter pre-chambers 4a1, 4a2, 4a3, 4a4 are replaced by altogether sixteen inlets. All the air supplied by way of the first flowpath 2a into the sixteen first nozzles 3a is led into a single annular space so that the body in which in Fig. 17 are the pre-chambers is here in Fig. 18 disintegrated into sixteen bodies 1000. Each body 1000 has its first attachment wall 14a to which after leaving the first nozzles 3a attach the first radial routes 5ba directed towards the first central exit 7a. Also, each body 1000 has its first antipodal wall 15a the end of which is directed tangentially into the space that forms the first vortex chamber 6a. Since in the centre of the first vortex chamber 6a collide altogether sixteen radial inflows (of which only a single representative is shown in Fig. 18) the symmetry of flows is secured and with it also the low pressure drop across the first vortex chamber 6a in the regime with absence of rotation. As soon as air from the connection channel 20 starts to flow from the first mouths 13a, the air flow through the first nozzles 3a is separated from the first attachment walls 14a and follows the first antipodal wall 15a. These walls guide it - in a manner similar to the first tangential route 5aa presented in Fig. 11 - tangen-

tially into the first vortex chamber 6a. Due to the large number of tangential inflows also this regime is characterised by welcome symmetry of the flowfield.

[0058] Obviously, the first vortex chamber 6a arranged according to Fig. 18 has all prerequisites for high efficiency, i.e. on one hand the very low pressure drop in the radial flow regime and on the other hand very high pressure drop in the tangential flow regime with rotation. The only disadvantage of this layout is the large diameter, especially with the system of the bodies 1000 on its outer circumference and, in addition, the annular space for air distribution into the first nozzle 3a.

Example 9

[0059] In some applications calling for compactness of the unit this large diameter may be a disadvantage and a more compact layout may be in demand. One solution is presented in Fig. 19. Essentially, the principle of operation is the same as in Fig. 18. The radial layout of the bodies 1000 in Fig. 18 is here in Fig. 19 replaced by an axial layout. The picture shows one from the two identical vortex devices in a unit. At the left-hand side in Fig. 19 there is the entrance by axial first flowpath 2a which leaves, also axially, on the right-hand side. The long conical diffuser (that improves the ratio of the pressure drops in the two regimes) is the first central exit 7a from the first vortex chamber 6a. The first vortex chamber 6a is of flat cylindrical shape. The first distribution cavity 8a with its first porous wall 9a connected directly to the first central exit 7a are not shown here.

[0060] The first vortex chamber 6a is here formed between the outer shell (only one half of which is shown, the other half being removed by imagined meridian section) and the axially symmetric central body 2000 similarly shown with one half removed. Coming from the left-hand side, the first flowpath 2a passes through the annular space between the outer shell and the central body 2000. Positioned in this annular space are bodies 1000 with the first mouth 13a in each of them. On the inflow side, the spaces between the bodies 1000 form the first nozzles 3a. Exit from the first nozzles 3a is directed axially, i.e. in parallel with the axis of the device. Further downstream, in the direction of the exit from the first nozzle 3a, one of the sides of the bodies 1000 forms the first attachment wall 14a. The opposite first antipodal wall 15a wall of bodies 1000 is inclined and curved so as to lead into the first vortex chamber 6a tangentially. Between this wall and the attachment wall 14a is inserted the splitter 50 (similar as shown in Fig. 11).

[0061] If a small pressure drop across the first vortex chamber 6a is requested, there is to be no air flow issuing from the first mouth 13a. The air of the first flowpath 2a enters the first nozzle 3a, is accelerated there and directed to the first attachment wall 14a. This guides it axially and then, following the downstream side of the central body 2000 it is turned into the radial inflow into the first vortex chamber 6a where there is no rotation. The

pressure in the first mouth 13a is very low - and it is further decreased by the conversion taking place in the diffuser of the first central exit 7a.

[0062] This low pressure would induce an air flow into the connecting channel 20 (not drawn in Fig. 19) leading towards the first mouth 13a. From the second mouth 13b where the pressure is higher. When the flow in the connecting channel 20 gains momentum, it will assume a magnitude sufficient for separating the axial air flow from the first attachment wall 14a and switching it towards the first antipodal wall 15a that guides it into the tangential route 5a past the splitter 50. This tangential inflow starts the rotation in the first vortex chamber 6a. Pressure difference across it increases. This leads to flow direction reversal in the connecting channel 20 and subsequently to the next half of the pulsation cycle.

Industrial applicability

[0063] Small gas bubbles in a liquid, that may be economically generated by the unit according to this invention, are desirable in a large number of industrial processes where already now air (or gas in general) bubbles are already made and used. The decrease of the bubble size means that for a given volume of air is much larger the overall surface area across which gas diffused into the liquid - and the smaller size also decreases the velocity of bubble rising up to the liquid surface. As a result the gas diffusion is intensified and this is done by compact units characterised by economical operation. The most important envisaged application of the unit is producing tiny air bubbles in processed waste water, where the actual processing is done by bacteria that in present waste water processing plants die due to the lack of oxygen and cannot fulfil their task completely. With the aeration by very tiny air bubbles the life of the bacteria is longer and at the same time the smaller financial expenditure is needed for supplying the compressed air. Similar advantages for providing more gas transfer surface into the liquid are there in oxidative leaching of plutonium, photoresist removal from silicon wafers, separation of various materials by froth flotation, yeast production, sonochemical synthesis, salvaging crude oil from exhausted oil wells, and growing unicellular organisms and algae as the basis of food chain.

List of identification numbers :

[0064]

1	supply channel
2a	first flowpath
2b	second flowpath
3a	first nozzle
3b	second nozzle
4a	first pre-chamber
4a1	first perimeter pre-chamber

(continued)

4a2 second perimeter pre-chamber
 4a3 third perimeter pre-chamber
 4a4 fourth perimeter pre-chamber
 4b second pre-chamber
 5a tangential route
 5b radial route
 5aa first tangential route
 5ba first radial route
 5ab second tangential route
 5bb second radial route
 6a first vortex chamber
 6b second vortex chamber
 7a first central exit
 7b secondfirst central exit
 8a first distribution cavity
 8b second distribution cavity
 9a first porous wall
 9b second porous wall
 10a first diverting location
 10b second diverting location
 11 carrying pipe
 13a first mouth
 13b second mouth
 14a first attachment wall
 14b second attachment wall
 15a first antipodal wall
 15b second antipodal wall
 16 guiding blade
 20 connection channel
 46a first nose
 46b second nose
 50 splitter
 91 bottom plate
 92 main plate
 93 partition
 94 distribution plate
 95 top plate
 100 symmetry axis
 101 vortex chamber axis
 146a first orifice
 146b second orifice
 214 extension
 206 recession
 901 screw holes
 902 dowel holes
 931 interconnection holes
 941 interconnection channel
 950 exit holes
 951 supporting rib
 1000 bodies
 2000 central body

Claims

1. Unit of a generator of gas bubbles in a liquid connected to a supply of the gas into a vessel containing the liquid **characterised by** containing a supply channel (1) for the flow of the supplied gas, which is branched into at least two concurrent flowpaths (2a, 2b) each of which contains six mutually series-connected components, namely a nozzle (3a, 3b), a pre-chamber (4a, 4b), a vortex chamber (6a, 6b), a central exit (71, 7b), a distribution cavity (8a, 8b), and a porous wall (9a, 9b) open onto the vessel with the liquid, where the nozzle (3a, 3b) is directed into the pre-chamber (4a, 4b) and downstream from the nozzle (3a, 3b) is each flowpath (2a, 2b) bifurcated into two routes, namely a tangential route (5a) and a radial route (5b), both entering the vortex chamber (6a, 6b) where the radial route (5b) is adjacent to an attachment wall (14a, 14b) directed into the central exit (7a, 7b) while the diverting location (10a, 10b), at the beginning of the two routes (5a, 5b) between the nozzle (3a, 3b) and the beginning of the attachment wall (14a, 14b), contains mouth (13a, 13b) of the connection channel (20) connecting the first flowpath (2a) and the second flowpath (2b).
2. Unit of a generator of gas bubbles in a liquid connected to the supply of the gas into the vessel containing the liquid according to the claim 1 **characterised in that** between the pre-chamber (4a, 4b) and the axisymmetric vortex chamber (6a, 6b) lead both the tangential route (5a) as well as the radial route (5b) through a single common orifice (146a, 146b) and the pre-chamber (4a, 4b) has opposite to the attachment wall (14a, 14b) a antipodal wall (15a, 15b) that is inclined to it by an angle α larger than 16 angular degrees and further that between the antipodal wall (15a, 15b) and the vortex chamber (6a, 6b) there is a protruding nose (46a, 46b).
3. Unit of a generator of gas bubbles in a liquid connected to the supply of the gas into the vessel containing the liquid according to the claim 1 **characterised in that** two orifices (146a, 146b) leading into the same vortex chamber (6a, 6b), namely one orifice (146aa, 146ab) for the tangential route (5a) and another orifice (146ba, 146bb) for the radial route (5b) the said routes (5a, 5b) being formed each on a different side of the splitter (50).
4. Unit of a generator of gas bubbles in a liquid connected to the supply of the gas into the vessel containing the liquid according to the claims 1 to 3, **characterised in that** a guiding blade (16) shaped into an arch is positioned inside the vortex chamber (6a, 6b).
5. Unit of a generator of gas bubbles in a liquid con-

connected to the supply of the gas into the vessel containing the liquid according to the claims 1 to 3 **characterised in that** the first flowpath (2a) and/or the second flowpath (2b) is divided into two or more concurrent ways connected by means of their peripheral pre-chambers (4a1, 4a2, 4a3, 4a4) to a common vortex chamber (6a, 6b).

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6. Unit of a generator of gas bubbles in a liquid connected to the supply of the gas into the vessel containing the liquid according to the claims 1 to 3 **characterised in that** the upper wall of the vortex chamber (6a, 6b) and/or the bottom wall of the vortex chamber (6a, 6b) has a shape of a cone.

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7. Unit of a generator of gas bubbles in a liquid connected to the supply of the gas into the vessel containing the liquid according to any of the claims 1 to 6 **characterised in that** it contains components: the top plate (95) provided with exit holes (950) and under it a woven metal textile the part of which under the exit holes (950) forms the porous wall (9a, 9b) of the distribution cavities (8a, 8b) where fastened to the top plate (95) under the metal textile is the distribution plate (94) to which is fastened partition (93) containing central exits (7a, 7b), the latter connected to the main plate (92) to which is fastened the bottom plate (91) and with advantage the carrying pipe (11) connected to the top plate (95) while the pre-chamber (4a, 4b) and the vortex chamber (6a, 6b) are made in the main plate (92) and the distribution cavities (8a, 8b) are made in the distribution plate (94a, 94b).

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8. Unit of a generator of gas bubbles in a liquid connected to the supply of the gas into the vessel containing the liquid according to the claim 7 **characterised in that** between the exit holes (950) are supporting ribs (951).

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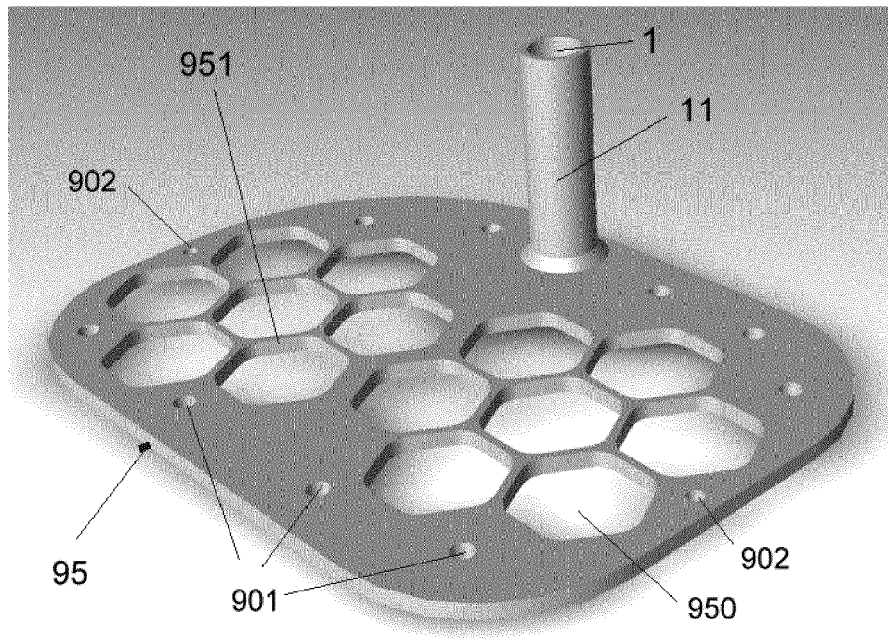


Fig. 1

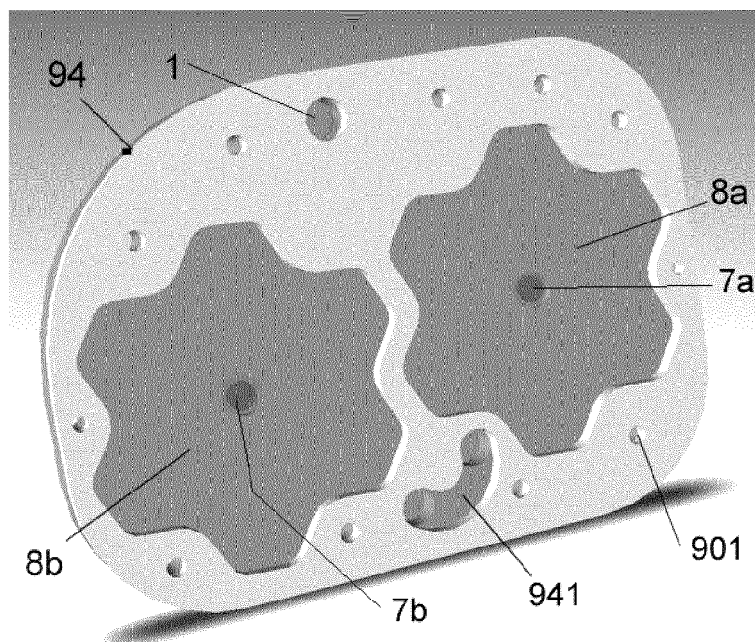


Fig. 2

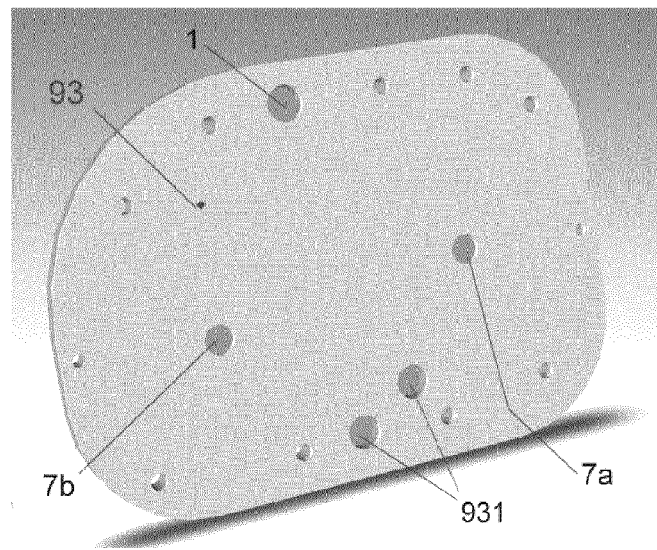


Fig. 3

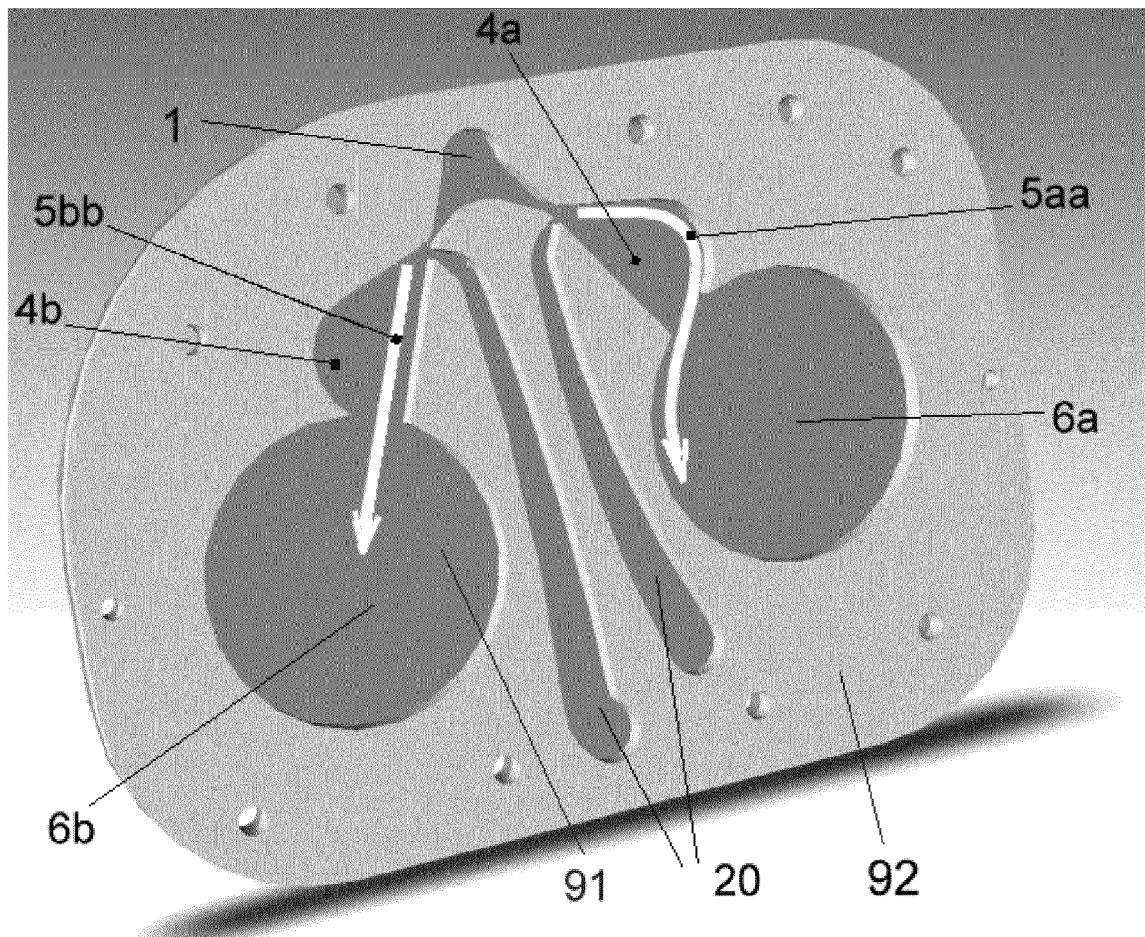


Fig. 4

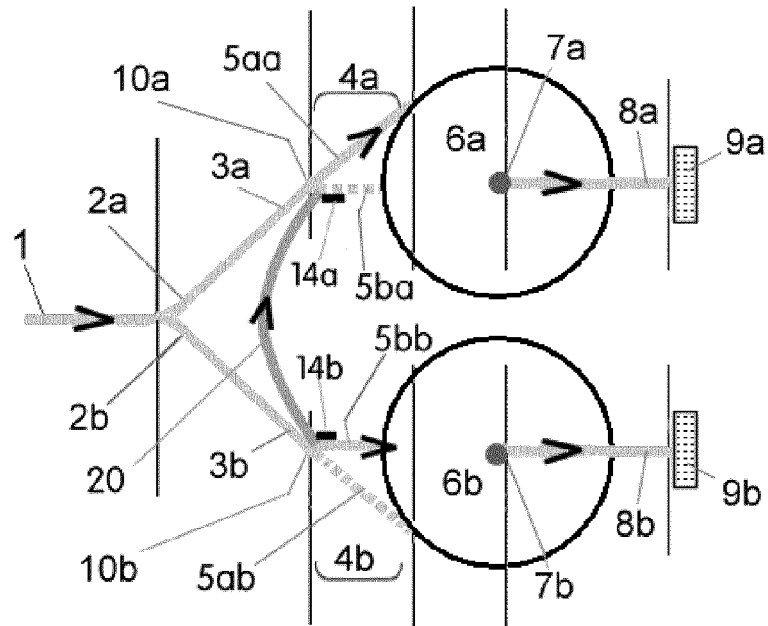


Fig.5

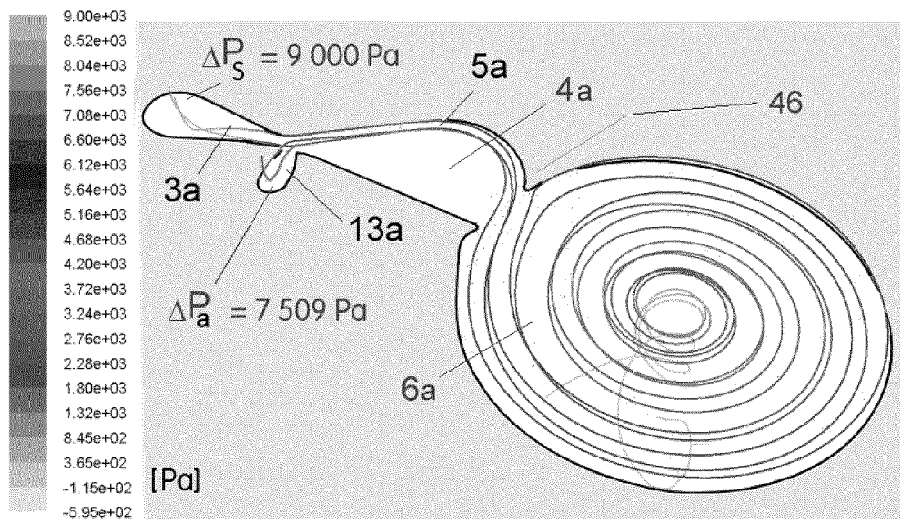


Fig. 6

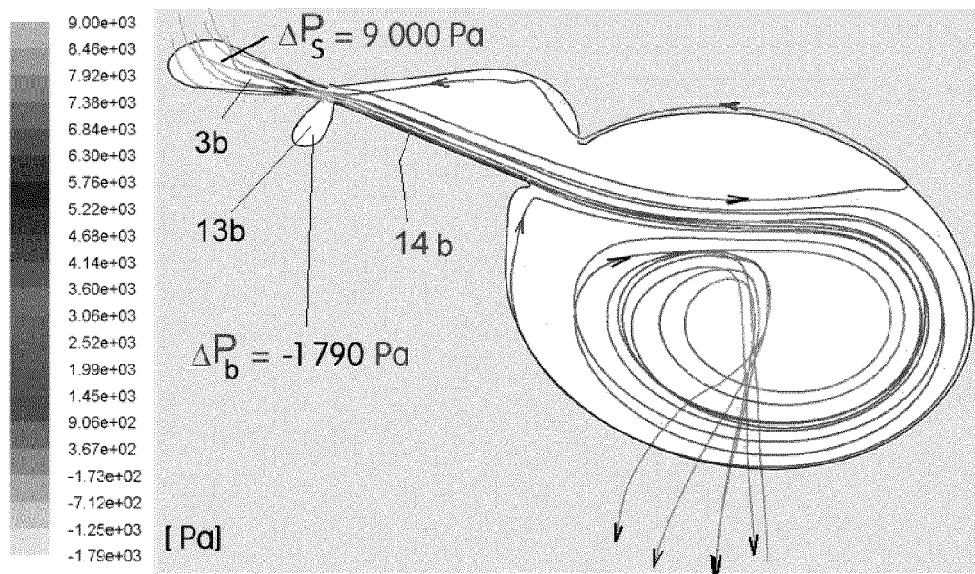


Fig. 7

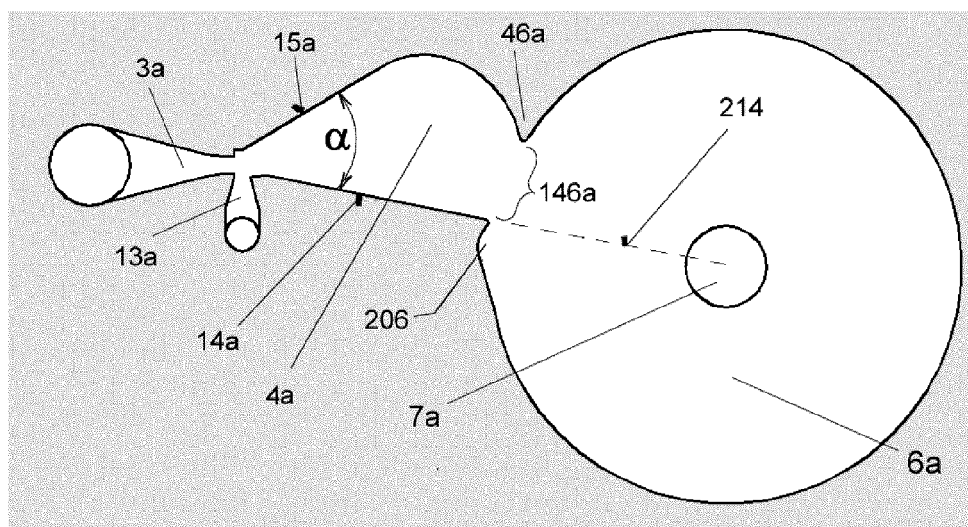


Fig. 8

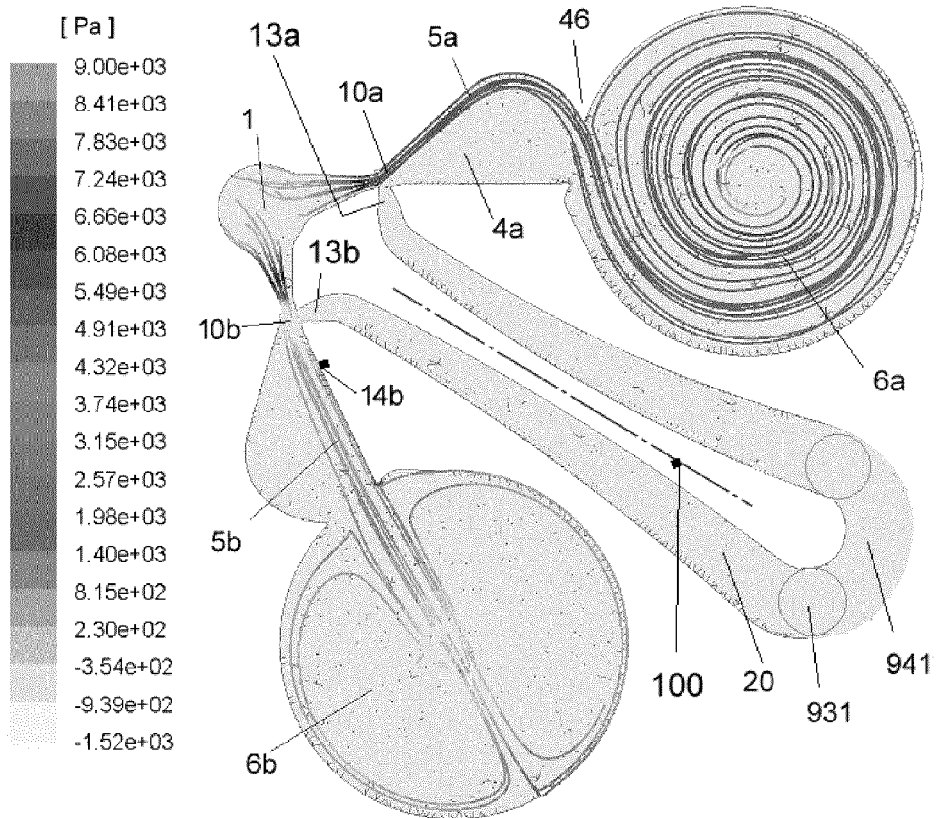


Fig. 9

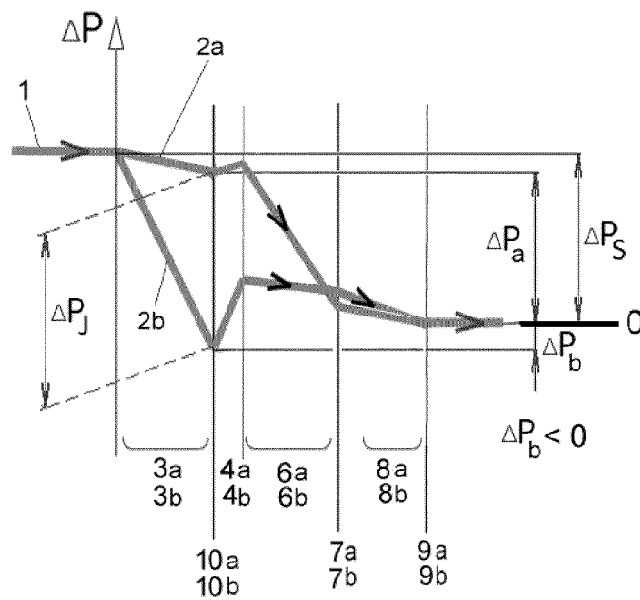


Fig. 10

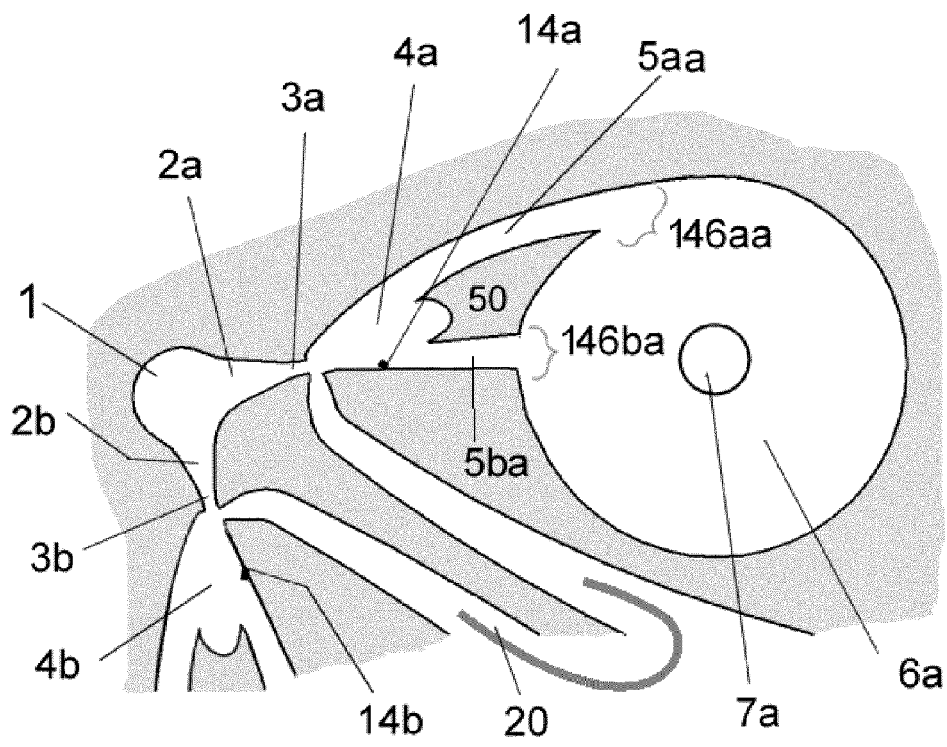


Fig. 11

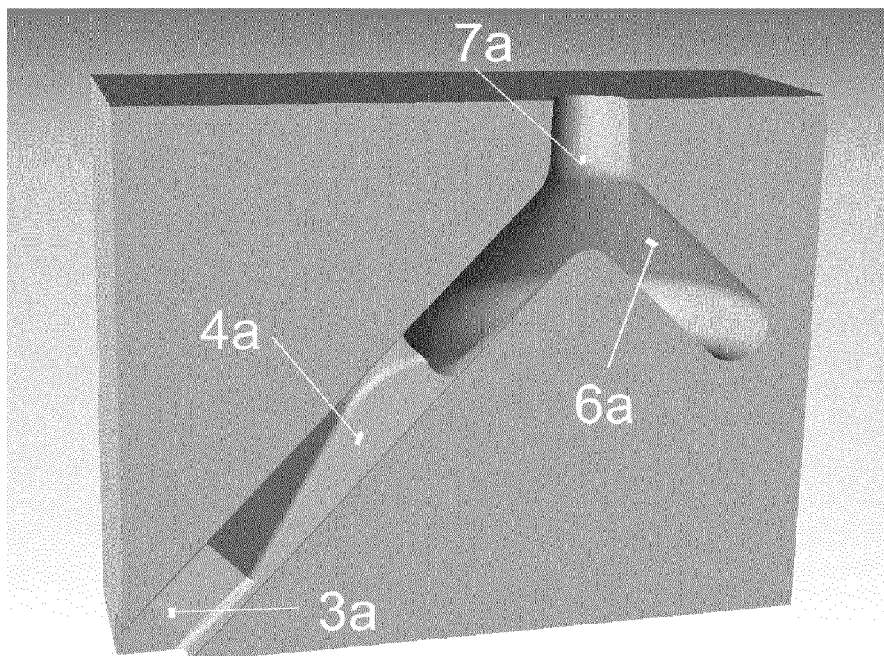


Fig. 12

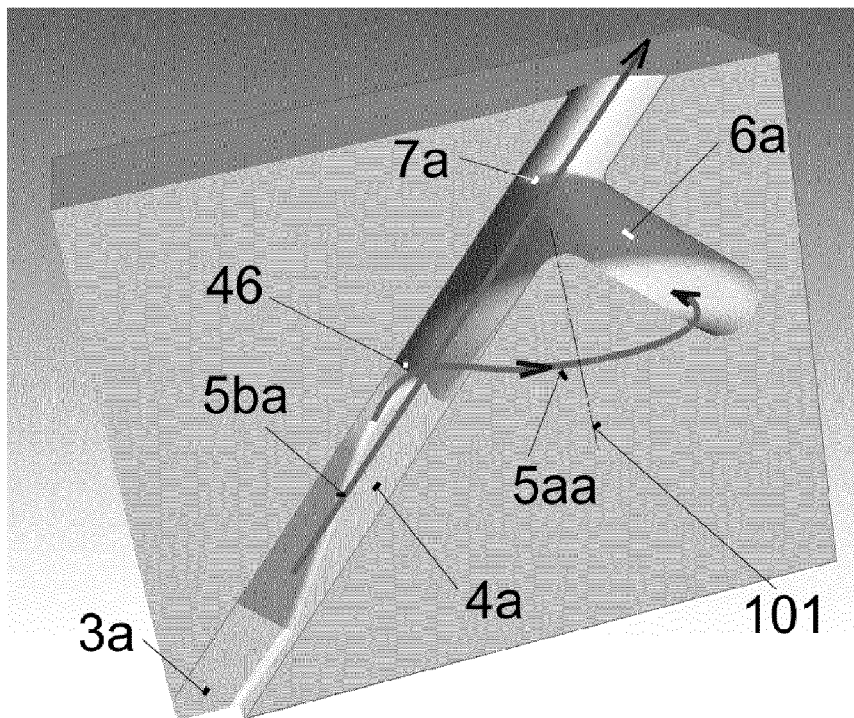


Fig. 13

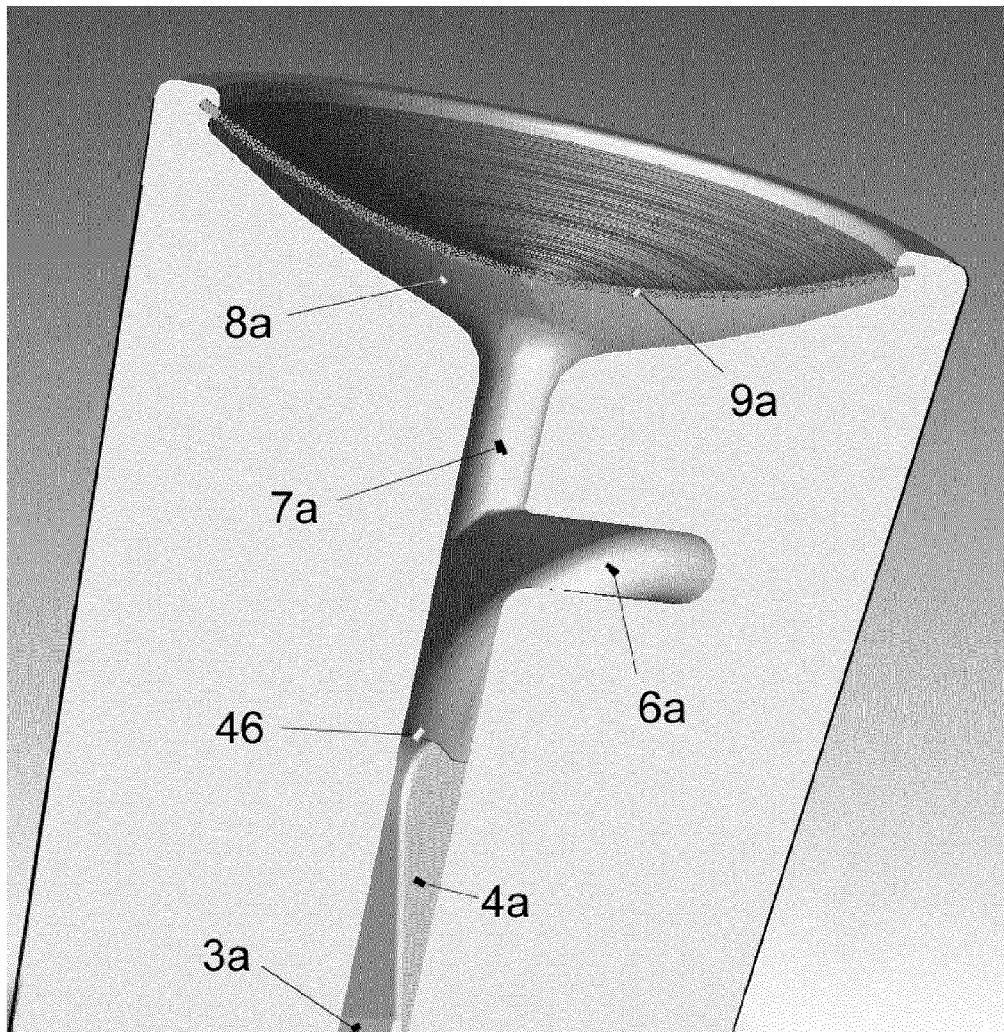


Fig.14

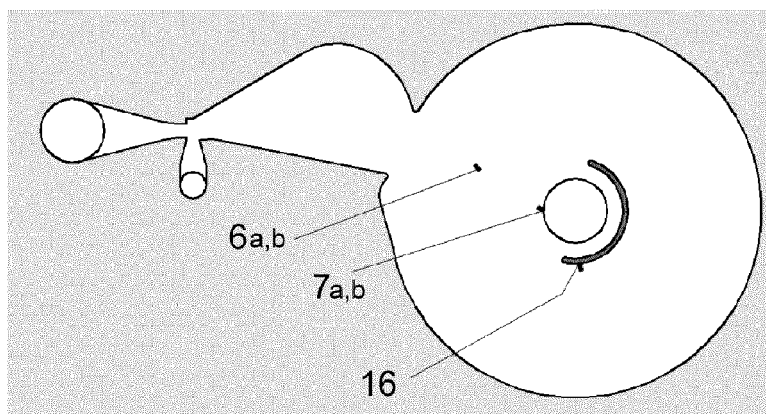


Fig. 15

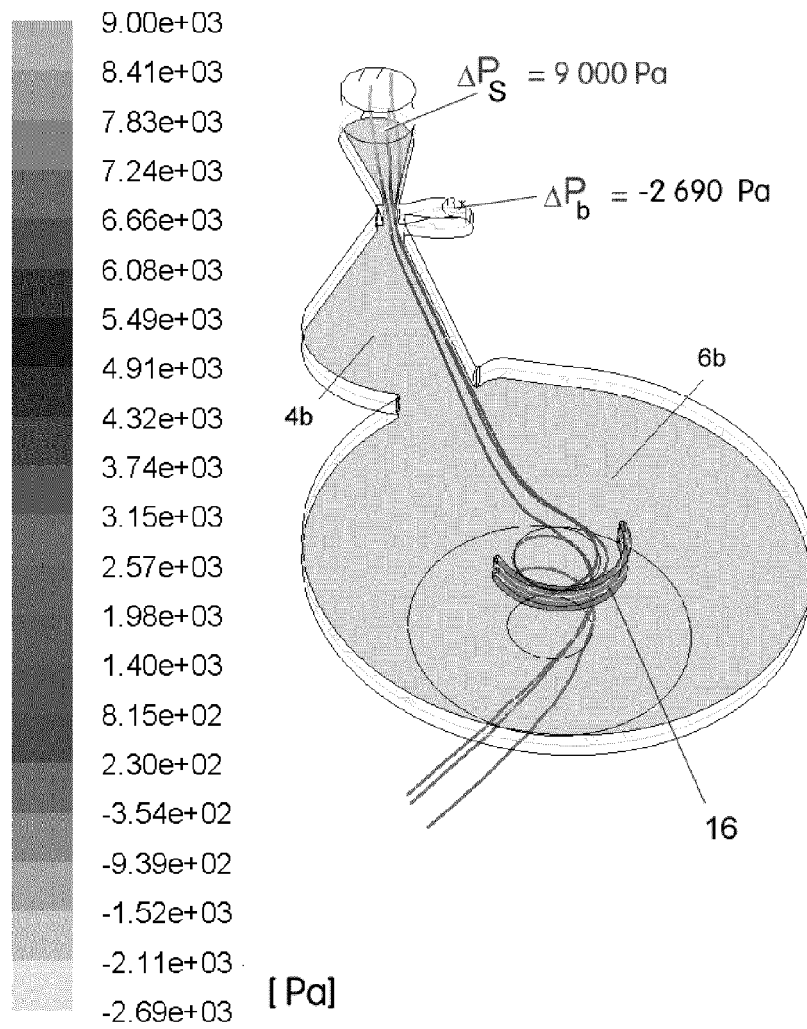


Fig. 16

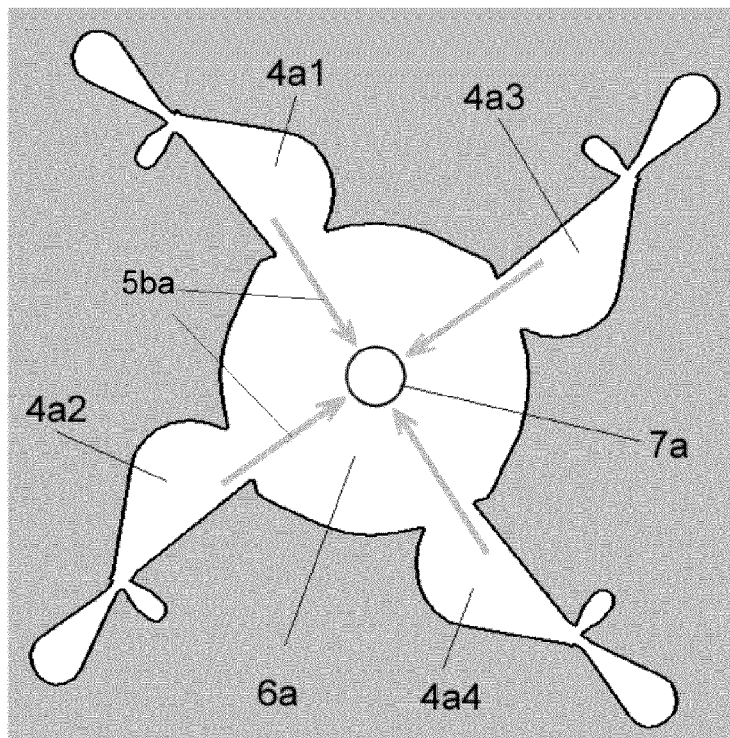


Fig. 17

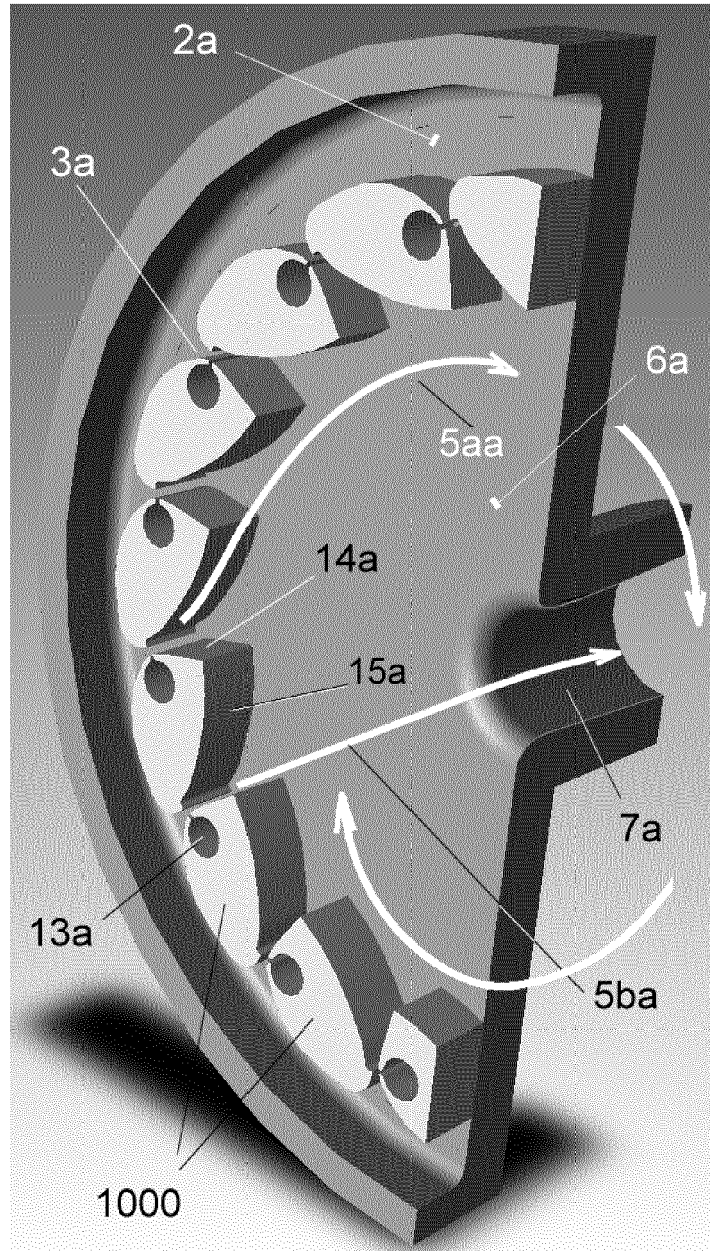


Fig. 18

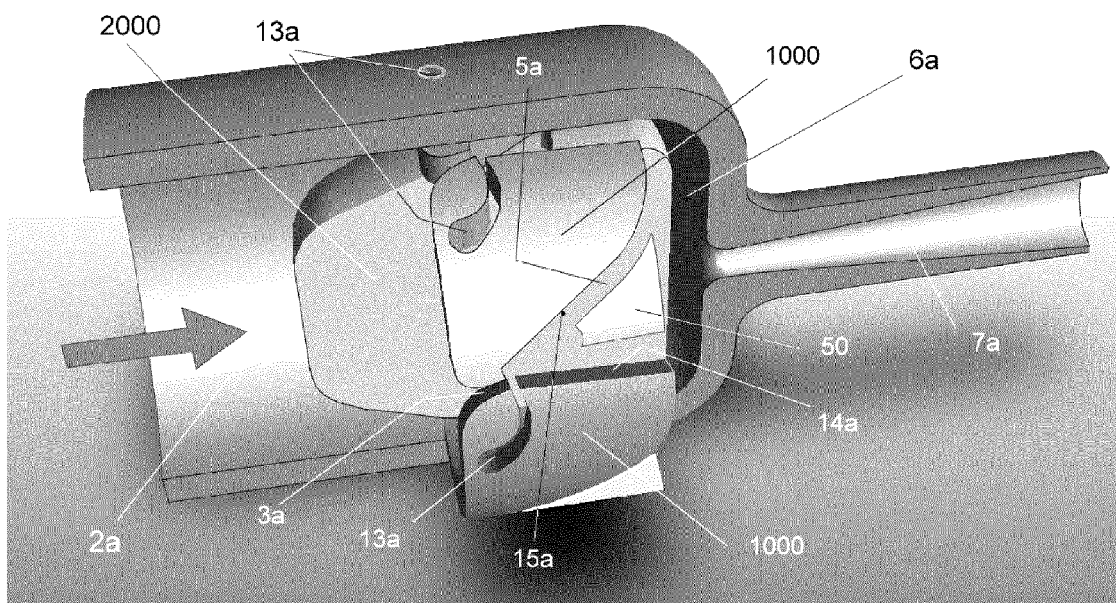


Fig. 19



EUROPEAN SEARCH REPORT

Application Number
EP 12 19 9083

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 11 March 2013	Examiner Real Cabrera, Rafael
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

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