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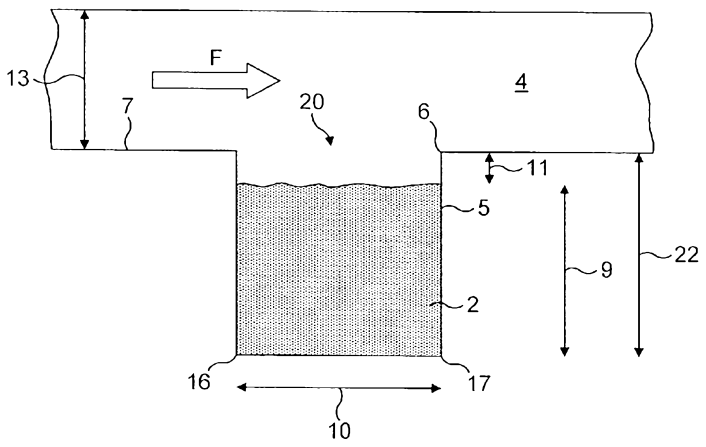

FIG. 1

(57) **Abstract**: The invention relates to a device (1) for inhalation of at least one air stream carrying a dose of medicament powder (2). The device comprises a powder-containing cavity (5) which opens into a flow passage (4). The flow passage is arranged to direct an inhalation air flow across the cavity opening. A circulating flow is thereby induced in the cavity (5) by the phenomenon of shear driven cavity flow. Powder is entrained in the circulating flow and deaggregated before exiting the cavity and becoming entrained in the flow of air along the flow passage (4).

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DISPENSER AND METHOD FOR ENTRAINING POWDER IN AN AIRFLOW

Field of the invention

The present invention relates to a device and method for entraining in an airflow a medicament powder contained in a cavity. The present invention also relates to a medical dispenser, comprising a powder-containing cavity.

Background of the invention

There are many devices for administering powdered medicaments to the lungs, which employ propellants, such as compressed gases, e.g. air, or liquefied gas propellants, to dispense and disperse the medicament.

There are also a number of known breath actuated inhalation devices for administering powdered medicaments to the lungs, which have mouthpieces through which the medicament is inhaled. British Patent Specification Nos. 1 521 000, 1 520 062, 1 472 650 and 1 502 150 disclose more complex devices in which a complete capsule is inserted into the device thus ensuring no spillage of medicament prior to inhalation, and access to the medicament is gained by piercing the capsule or cutting it in half, inside the dispensing device. On inhalation the air flows into or through the capsule and the powder within is released into the air stream and flows towards the mouth.

U.S. Patent Specification No. 4,210,140 discloses a device in which access to the powdered medicament is gained by pulling the halves of the capsule apart so that the medicament is emptied to a suitable position for entrainment in the airflow caused by inhalation.

US Patent No. 6,655,381B2 relates to a pre-metered dose assembly for consistently supplying precise doses of medicament for a breath-actuated dry powder inhaler. The assembly includes a cap defining a dry powder delivery passageway for providing air to a dry powder supply port of a swirl chamber of a breath-actuated dry powder inhaler, and a magazine including a plurality of reservoirs for holding pre-metered

doses of dry powder. One of the magazine and the cap is movable with respect to the other of the magazine and the cap for sequentially positioning the reservoirs within the delivery passageway of the cap. A breath-induced low pressure at an outlet port of the inhaler causes an airflow through the dry powder delivery passageway of the assembly and into the dry powder supply port that entrains dry powder from the reservoir positioned in the passageway for inhalation by a patient using the inhaler. The passageway is provided with a venturi in the passageway by the reservoir to create a flow through the reservoir and bring the powder there from.

US Patent No. 4,446,862 (Baum et al.) describes an inhaler device in which access to the powdered medicament is gained by pulling the halves of a capsule apart, leaving the lower half of the capsule retained in an upright position in the device, with its open end flush with the lower surface of a disc shaped inhalation chamber. Spaced around half the circumference of the chamber are a number of air inlets and, opposite these, a larger air outlet leading to a mouthpiece. On inhalation, air is drawn through the chamber and across the open mouth of the capsule. It is stated that this may create a resonance effect in the capsule, similar to the effect which causes a sound to be produced by blowing across the opening of a bottle.

US published patent application number 2009114220 (Boehringer) discloses a powder inhaler device in which a powder cavity is provided with an air outlet opening into the lower surface of an air flow path which narrows in the region of the outlet opening. The cavity also has an air inlet which does not open into the flow path. A venturi is created by the narrowing flow path adjacent the outlet, giving rise to low pressure in this area when flow is generated by a user inhaling. Air is thereby drawn through the cavity from the inlet to the outlet and then into the flow path.

US2009/0084379 (Baxter) describes a single dose inhaler suitable for insulin. The medicament is stored in a cavity with a round or oval shaped opening. The cavity has a depth greater than its length in the flow direction. A flow passage from an inlet to a mouthpiece passes across the top of the cavity; the floor and ceiling of the passage are smoothly curved and diverge on the upstream and downstream sides of the cavity, with the narrowest part of the passage adjacent the cavity. A “driven cavity flow” is

said to be created in the cavity so that powder is drawn out of the cavity and into the air flow.

WO2009/152477 (Mannkind) discloses a single dose inhaler suitable for insulin, with a medicament storage cavity which is deeper than it is long in the flow direction. The cavity has a lid in which one or more outlet holes are formed, whilst an inlet is formed in the upper downstream wall of the cavity. In use, air is drawn into the inlet and a circulating air flow is created which exits upwardly out of the outlet hole(s) in the lid.

In spite of the numerous prior art devices there is a need for a device, particularly a multi-cavity inhaler device, which is simple in design and therefore inexpensive, compact in size and also simple to operate, but which also allows for efficient emptying of a cavity of powder. Consistent and efficient emptying is important partly to avoid wastage of expensive medicament by leaving it in the device, but more importantly to avoid residual powder contaminating the device and being inadvertently inhaled on subsequent uses of the device.

There is also a need for a device which efficiently deaggregates powder before being administered. It is desirable for the deaggregation process to result in a significant proportion of the powder particles being in a certain aerodynamic size range. This is often referred to as classifying the powder particles. Various ways of enabling deaggregation are described in the prior art. For example, tortuous flow paths can cause deaggregation as particles impact the walls of the flow path. Alternatively, obstructions can be placed in the flow path downstream of the powder cavity or reservoir. Vibrating or shaking is another possibility. US4,446,862, discussed above, provides for the capsule to be moved rapidly on inhalation to loosen the powder contents and thereby aid deaggregation of highly cohesive or compacted powders.

Devices employing deaggregation features in the downstream flow passage may become clogged or contaminated in use, since medicament powder may accumulate on these downstream features. It is of course desirable to reduce or avoid the risk of administering an inaccurate amount of medicament powder. Where powder accumulates on downstream deaggregation features, a risk is that accumulated powder

from several doses may dislodge suddenly from these downstream features (e.g. if the device is dropped) resulting in the patient receiving a significant over-dose.

The trend in dry powder inhaler devices is to have shallow cavities into which flow is directed in order to entrain particles and empty the cavity efficiently. Especially for larger doses of powder, the use of shallow cavities can result in devices which are relatively large, since such a cavity may occupy a relatively large area.

The inventors have found, surprisingly, that a relatively deep cavity may be emptied very efficiently by optimizing the design parameters of the device to maximize the phenomenon of shear driven cavity flow in the powder cavity. The inventors have investigated a number of different cavity shapes and geometric parameters for a cavity and the flow path over the cavity, and compared emptying and deaggregating efficiency for these using both computational fluid dynamics techniques and physical prototypes.

The concept of shear driven cavity flow is, generally speaking, that a rotating flow in a cavity may result from passing a fluid stream across the opening of the cavity (distinct from directing flow into the cavity or using an airflow to create low pressure by the venturi effect above an opening of the cavity to draw a fluid stream through it). The flow tends to rotate in a cylindrical pattern.

US4,446,862, referred to above, describes a device in which a stream of air is passed across the opening of the separated lower half of a standard pharmaceutical capsule, thereby entraining powder. The inventors of the present invention believe that some shear driven cavity flow may occur in this prior device and that this phenomenon may partially explain the reported results. However, the inventors believe shape of the cavity may not allow the cylindrically rotating flow pattern characteristic of shear driven cavity flow to develop.

US2009//0084379 (Baxter) referred to above appears to use the shear driven flow phenomenon, but again the inventors believe the shape of the cavity and/or flow path may not be optimal.

It is somewhat counter-intuitive that generating a cylindrical rotating flow in a powder-containing cavity may result in fast and effective emptying of the cavity, rather than simply causing powder to be entrained in the rotating flow. However, the inventors of the present invention have found that powder may be quickly transferred from the rotating flow to the linear flow over the cavity, rather than remaining for a long period entrained in the rotating flow.

The inventors have found that the shear driven cavity flow effect, preferably in a relatively deep cavity, may be optimized by manipulating one or more parameters such as flow path design, cavity shape, pressure drop, flow velocity or volume flow rate. The inventors have found, surprisingly, that not only fast cavity emptying but also deaggregation or classifying of powder in the cavity can be achieved very effectively in a deep cavity by employing the shear driven cavity flow phenomenon.

Summary of the invention

According to one aspect of the invention, there is provided a dry powder inhaler device for dispensing an air stream carrying a dose of medicament powder, the device comprising a flow passage and a powder storage cavity having an opening, wherein the cavity opening is in a wall of the flow passage and the flow passage is arranged to direct a flow of air across the cavity opening, and wherein (i) the cavity opening has a quadrilateral shape, such as rectangular or trapezoidal, (ii) the length of the cavity opening in the flow direction is (i) between 50% and 150% of the cavity depth, and (ii) at least 80% of the maximum length of the cavity in the flow direction, (iii) the maximum height of the flow passage adjacent the cavity is between 0.5mm and 4mm, preferably between 0.5mm and 3mm, more preferably between 1mm and 2mm, and (iv) the lower front and/or rear edges of the cavity, with respect to the flow direction, have a radius of between 0.5 and 3 mm, preferably between 1.5 and 2.5 mm, more preferably between 1.75 and 2.25 mm.

The fillet radii of the opening may be 0.001mm to 0.5mm, preferably 0.01mm to 0.3mm. The inventors believe that a cavity opening of this shape may promote the cylindrical flow pattern characteristic of shear driven cavity flow more effectively than, say, a circular or oval opening. The opening may have an aspect ratio in the range 1.5 to 4.0, more preferably 1.8 to 3.5, still more preferably 2.6 to 3.2. The larger dimension is preferably aligned with the direction of flow in the flow passage.

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Preferably, the length of the cavity opening in the flow direction may be between 105% and 140% of the cavity depth, more preferably between 110% and 135%. The inventors believe that this may promote shear driven flow in the cavity.

The flow passage is preferably contoured to avoid directing flow into the cavity, for example the cavity opening may be formed in a flat wall of the flow passage, preferably also with a parallel wall opposite the cavity opening.

The inventors believe that an inhaler with the geometry and dimensions specified above may, in use by a human patient, generate airflow of the correct characteristics to result in efficient emptying and deaggregation of powder contained in the cavity.

Preferably, the flow passage may be arranged to create a substantially unidirectional flow across the cavity opening. This would be in contrast, for example, to the flow across the cavity described in US4,446,862 which is (in plan view) fan shaped: although this flow has an overall direction which could be said to be along the line of symmetry of the fan shape, it could not be described as "unidirectional". Furthermore, the height of the flow passage adjacent the cavity in US4,446,862, being 10mm or more, may allow for substantial vertical deviations in the flow.

Preferably, the maximum width (see definition below) of the flow passage in the region of the cavity may be between 2mm and 6mm. The cross sectional area of the passage adjacent the cavity may therefore be in the range 1mm^2 to 20mm^2, preferably 3mm^2 to 10mm^2.

According to another embodiment of the invention, a dry powder inhaler device for dispensing an air stream carrying a dose of medicament powder comprises a flow passage and a powder storage cavity having an opening, wherein the cavity opening is in a wall of the flow passage and the flow passage is arranged to direct a flow of air across the cavity opening, and wherein the length of the cavity opening in the flow direction is (i) between 50% and 150% of the cavity depth, and (ii) at least 80% of the maximum length of the cavity in the flow direction, characterized in that the maximum height of the flow passage immediately adjacent the cavity is between 0.5mm and 4mm.

Another factor which the inventors believe may promote shear driven cavity flow includes the geometry of the lower front and/or rear edges of the cavity, with respect to the flow direction. These may preferably have a radius of between 1 and 3mm, preferably between 1.5mm and 2.5mm (this is distinct from the fillet radii of the cavity opening and vertical corners/edges of the cavity, as mentioned above).

The cavity itself may have a depth as defined below between 3mm and 10mm, preferably between 4mm and 6mm. The maximum length in the flow direction may be between 3mm and 10mm, preferably between 4mm and 7mm. The average width of the cavity may be between 1mm and 5mm, preferably between 1.5mm and 3mm. As well as defining an appropriate volume for containing medicament powder in a dry powder inhaler, the inventors believe that these dimensions will promote effective emptying and deaggregation.

Initial work by the inventors was with a simple cuboid shaped cavity (see e.g. Figure 1). Physical models of such cavities were constructed, filled with powder and tested, the results being recorded using high speed video techniques. Cavity emptying similar to that shown in Figures 3a to 3d was observed. In an attempt to improve the performance, the cavity shape was modified to include a large radius (of the order of 2mm) on the lower upstream edge since this reflected the erosion pattern of the powder during the emptying process. This was found to improve the emptying of the cavity.

Further work using computational fluid dynamics techniques (described in more detail below) has resulted in the current best known shape for the cavity which has a large radius on the both the upstream and downstream lower edges of the cavity.

Preferably, a flow-perturbing member may project from a flow passage wall, the flow perturbing member being located with its most upstream extent between 1mm and 20mm upstream of the cavity, preferably between 2mm and 10mm, more preferably between 3mm and 7mm. The inventors believe that this flow perturbing member or members may increase the turbulence in the flow across the cavity, which in turn may increase the turbulence of the induced rotating flow in the cavity. The inventors

believe that this may increase the efficiency with which the cavity is emptied of powder.

Work using computational fluid dynamics techniques with different designs of flow-perturbing member has confirmed that a markedly increased performance can be obtained. The exact shape and lateral position of the member can have an effect, but is not critical.

The flow-perturbing member may project from a wall in which the cavity opening is formed (i.e. from the "floor" of the passage). The member may extend across the full height of the passage, or across the full width of the passage, but preferably it only extends over from 1% to 50%, more preferably from 1% to 20%, of the width and/or height of the passage. The cross sectional area of the member in the direction of the flow may be from 1 to 25% of the cross section of the flow passage (perpendicular to the flow) in the vicinity of the member. Preferably the cross section of the member is from 3 to 20%, more preferably 5 to 15% of the cross section of the flow passage in the vicinity of the member.

Preferably, a lid member may be associated with the cavity, movable between a first position in which the cavity is closed and a second position in which the cavity is open and the lid member provides part of the boundary of the flow passage.

In some circumstances, e.g. if it is required to administer two separate medicaments in the same inhalation, it may be desirable to have a second powder storage cavity opening into the flow passage, downstream of the first said cavity. The lid member mentioned above may close or open both cavities as it moves between its first and second positions.

The device may have a plurality of flow passages arranged around the circumference of a circle, the flow passages being arranged such that the flow direction is radial with respect to the said circle, at least one said powder storage cavity being associated with each flow passage. In this way, a conveniently shaped multi-dose inhaler may be provided. The cavities may be provided in a disc member, which may be arranged to be rotatable with respect to an inhaler mouthpiece, in order sequentially to bring into registry with the mouthpiece unused powder-containing cavities. In a device such as

this, it may be preferable for the cavity opening to have a trapezium shape with the line of symmetry located along the direction of flow in the flow passage. This arrangement may help to maximise the number of cavities which can be fitted into a given size of disc.

In a multi-dose device as described above, the flow direction may be radially outward, with an inlet near the centre of the device and a mouthpiece located at the periphery. In this case the direction of flow in a cavity with a trapezium shaped opening may be from the smaller to the larger end of the opening. Alternatively, the device may have an inlet at the periphery and a centrally located mouthpiece, in which case the flow across a trapezium shaped cavity may be from the larger to the smaller end.

According to another aspect of the invention, there is provided a device for dispensing an air stream carrying a dose of medicament powder, the device comprising (a) a powder storage cavity having a single opening and (b) a lid member movable between a first position in which the cavity is closed and a second position in which the cavity is open, wherein when the lid member is in the second position it provides part of the boundary of a flow passage, the cavity opening being in a wall of the flow passage and the flow passage being arranged to direct a flow of air across the cavity opening, and wherein (i) the cavity opening has a quadrilateral shape, such as a rectangular or trapezoidal, and (ii) the length of the cavity opening in the flow direction is between 50% and 150% of the cavity depth, and (iii) the lower front and/or rear edges of the cavity, with respect to the flow direction, have a radius of between 0.5 and 3mm, preferably between 1.5 and 2.5mm, more preferably between 1.75 and 2.25mm..

In some circumstances, e.g. if it is required to administer two separate medicaments in the same inhalation, it may be desirable to have a second powder storage cavity opening into the flow passage, the second cavity also being closed when the lid member in the first position and open when the lid member is in the second position. In another aspect, there is provided a dry powder inhaler device for dispensing an air stream carrying a dose of medicament powder, the device comprising a flow passage and a powder storage cavity having an opening, wherein the cavity opening is in a wall of the flow passage and the flow passage is arranged to direct a flow of air across the cavity opening, and wherein the length of the cavity opening in the flow direction

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is (i) between 50% and 150% of the cavity depth, and (ii) at least 80% of the maximum length of the cavity in the flow direction, wherein the flow passage adjacent the cavity has a cross sectional area in the range 1mm^2 to 20mm^2, preferably 3mm^2 to 10mm^2, and wherein the lower front and/or rear edges of the cavity, with respect to the flow direction, have a radius of between 0.5 and 3mm, preferably between 1.5 and 2.5mm, more preferably between 1.75 and 2.25mm.

In an inhaler for use by human patients, the total pressure drop across the device in use is normally between 2kPa and 6kPa. The pressure difference in the flow passage from one end of the cavity to the other will be somewhat less because of pressure losses in other parts of the inhaler device, but would normally be from 0.1kPa to 5kPa, preferably 0.5kPa to 2kPa. The flow passage dimensions referred to above may result in a pressure drop in this range for an inhaler designed for use by a human patient.

According to another embodiment of the invention, a dry powder inhaler device for dispensing an air stream carrying a dose of medicament powder comprises a flow passage and a powder storage cavity having only a single opening, wherein the cavity opening is in a wall of the flow passage and the flow passage is arranged to direct a flow of air across the cavity opening, and wherein the length of the cavity opening in the flow direction is between 50% and 150% of the cavity depth, characterized in that the maximum height of the flow passage immediately adjacent the cavity is between 0.5mm and 4mm.

According to another embodiment of the invention, a dry powder inhaler device for dispensing an air stream carrying a dose of medicament powder comprises a flow passage and a powder storage cavity having only a single opening, wherein the cavity opening is in a wall of the flow passage and the flow passage is arranged to direct a flow of air across the cavity opening, and wherein the length of the cavity opening in the flow direction is between 50% and 150% of the cavity depth, characterized in that the flow passage adjacent the cavity has a cross sectional area in the range 1mm^2 to 15mm^2, preferably 3mm^2 to 10mm^2.

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In another embodiment, the invention may be a dosage form comprising a compound or combination selected from the list which appears below, loaded into a device as described above.

It is believed that the shape of the cavity has an important effect on the performance. It is believed that, because the shear driven cavity flow phenomenon tends to produce a cylindrical rotating flow pattern, a cavity of generally rectangular or trapezoidal shape in plan view, at least for some of its depth, e.g. at least the upper half of the cavity (the half nearer the opening, based on the perpendicular distance from the cavity opening to the furthest extent of the cavity), will promote a rotating cavity flow. By plan view is meant the view looking at the cavity in a direction normal to the plane of the cavity opening (as defined). The longitudinal line of symmetry of the rectangular or trapezoidal opening preferably is oriented in the direction of the airflow in the flow passage.

In order to generate shear driven cavity flow, it is believed that the opening of the cavity should ideally have a cross sectional area which is of the same order as the maximum cross section of the cavity in a plane parallel to the cavity opening, e.g. at least 80% of the maximum cross section, preferably at least 90%, more preferably about 100%.

The cavity is provided with a headspace between the powder fill level (when the powder surface is level and parallel with the cavity opening) and the cavity opening; the headspace is preferably from 1 mm to 6mm.

Aspects of the invention also relate to a replacement magazine comprising a cavity or cavities charged with medicament powder for use in a device as described in any of the preceding paragraphs.

In further aspects, the invention also relates to a cavity disc for a dry powder inhaler, which may be shaped generally as a solid disc or as an annulus, the cavity disc comprising a plurality of powder-containing cavities arranged in a circular pattern on the disc, the cavities each having an trapezoid-shaped opening, which may be covered by a removable seal or lid, each cavity having a length in a radial direction which is from 50% to 150% of the depth of the cavity.

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Preferably, the length in a radial direction of each cavity may be at least 80% of the maximum length of the cavity in the said radial direction.

Preferably, the lower front and/or rear edges of the cavity (33), with respect to the flow direction, may have a radius of between 0.5 and 3mm, preferably between 1.5mm and 2.5mm, more preferably between 1.75mm and 2.25mm.

According to an embodiment of the invention, a device as described in any of the preceding paragraphs may be charged with medicament powder in the cavity or cavities.

The medicament powder may contain various active ingredients. The active ingredient may be selected from any therapeutic or diagnostic agent. For example, the active ingredient may be an antiallergic, a bronchodilator (e.g. a beta2-adrenoceptor agonist or a muscarinic antagonist), a bronchoconstrictor, a pulmonary lung surfactant, an analgesic, an antibiotic, a mast cell inhibitor, an antihistamine, an anti-inflammatory, an antineoplastic, an anaesthetic, an anti-tubercular, an imaging agent, a cardiovascular agent, an enzyme, a steroid, genetic material, a viral vector, an antisense agent, a protein, a peptide, a non-steroidal glucocorticoid Receptor (GR Receptor) agonist, an antioxidant, a chemokine antagonist (e.g. a CCR1 antagonist), a corticosteroid, a CRTh2 antagonist, a DP1 antagonist, an Histone Deacetylase Inducer, an IKK2 inhibitor, a COX inhibitor, a lipoxygenase inhibitor, a leukotriene receptor antagonist, an MPO inhibitor, a p38 inhibitor, a PDE inhibitor, a PPARγ agonist, a protease inhibitor, a statin, a thromboxane antagonist, a vasodilator, an ENAC blocker (Epithelial Sodium-channel blocker) and combinations thereof.

Examples of specific active ingredients that can be incorporated in the medicament powder include:

(i) antioxidants:- Allopurinol, Erdosteine, Mannitol, N-acetyl cysteine choline ester, N-acetyl cysteine ethyl ester, N-Acetylcysteine, N-Acetylcysteine amide and Niacin;

(ii) chemokine antagonists:- BX471 ((2R)-1-[[2-[(aminocarbonyl)amino]-4-chlorophenoxy]acetyl]-4-[(4-fluorophenyl)methyl]-2-methylpiperazine monohydrochloride), CCX634, *N*-{2-[((2*S*)-3-{[1-(4-chlorobenzyl)piperidin-4-yl]amino}-2-hydroxy-2-methylpropyl)oxy]-4-hydroxyphenyl}acetamide (see WO 2003/051839), and 2-{2-Chloro-5-{[(2S)-3-(5-chloro-1'H,3H-spiro[1-benzofuran-2,4'-piperidin]-1'-yl)-2-hydroxypropyl]oxy}-4-[(methylamino)carbonyl]phenoxy}-2-methylpropanoic acid (see WO 2008/010765), 656933 (N-(2-bromophenyl)-N'-(4-cyano-1H-1,2,3-benzotriazol-7-yl)urea), 766994 (4-({[({[(2R)-4-(3,4-dichlorobenzyl)morpholin-2-yl]methyl}amino)carbonyl]-amino}methyl)benzamide), CCX-282, CCX-915, Cyanovirin N, E-921, INCB-003284, INCB-9471, Maraviroc, MLN-3701, MLN-3897, T-487 (N-{1-[3-(4-ethoxyphenyl)-4-oxo-3,4-dihydropyrido[2,3-d]pyrimidin-2-yl]ethyl}-N-(pyridin-3-ylmethyl)-2-[4-(trifluoromethoxy)phenyl]acetamide) and Vicriviroc

(iii) Corticosteroids: -Alclometasone dipropionate, Amelometasone, Beclomethasone dipropionate, Budesonide, Butixocort propionate, Ciclesonide, Clobetasol propionate, Desisobutyrylciclesonide, Etiprednol dicloacetate, Fluocinolone acetonide, Fluticasone Furoate, Fluticasone propionate, Loteprednol etabonate (topical) and Mometasone furoate.

(iv) DP1 antagonisits:- L888839 and MK0525;

(v) Histone deacetylase inducers:- ADC4022, Aminophylline, a Methylxanthine or Theophylline;

(vi) IKK2 inhibitors:- 2-{[2-(2-Methylamino-pyrimidin-4-yl)-1H-indole-5-carbonyl]-amino}-3-(phenyl-pyridin-2-yl-amino)-propionic acid;

(vii) COX inhibitors:- Celecoxib, Diclofenac sodium, Etodolac, Ibuprofen, Indomethacin, Meloxicam, Nimesulide, OC1768, OC2125, OC2184, OC499, OCD9101, Parecoxib sodium, Piceatannol, Piroxicam, Rofecoxib and Valdecoxib;

(viii) Lipoxygenase inhibitors:- Ajulemic acid, Darbufelone, Darbufelone mesilate, Dexibuprofen lysine (monohydrate), Etalocib sodium,

Licofelone, Linazolast, Lonapalene, Masoprocol, MN-001 , Tepoxalin, UCB-35440, Veliflapon, ZD-2138, ZD-4007 and Zileuton ((±)-1-(1-Benzo[b]thien-2-ylethyl)-1-hydroxyurea);

(ix) Leukotriene receptor antagonists:- Ablukast, Iralukast (CGP 45715A), Montelukast, Montelukast sodium, Ontazolast, Pranlukast, Pranlukast hydrate (mono Na salt), Verlukast (MK-679) and Zafirlukast;

(x) MPO Inhibitors:- Hydroxamic acid derivative (N-(4-chloro-2-methyl-phenyl)-4-phenyl-4-[[(4-propan-2-ylphenyl)sulfonylamino]methyl]piperidine-1-carboxamide), Piceatannol and Resveratrol;

(xi) Beta2-adrenoceptor agonists:- metaproterenol, isoproterenol, isoprenaline, albuterol, salbutamol (e.g. as sulphate), formoterol (e.g. as fumarate), salmeterol (e.g. as xinafoate), terbutaline, orciprenaline, bitolterol (e.g. as mesylate), pirbuterol, indacaterol, salmeterol (e.g. as xinafoate), bambuterol (e.g. as hydrochloride), carmoterol, indacaterol (CAS no 312753-06-3; QAB-149), formanilide derivatives e.g. 3-(4-{[6-({(2R)-2-[3-(formylamino)-4-hydroxyphenyl]-2-hydroxyethyl}amino)hexyl]oxy}-butyl)-benzenesulfonamide; 3-(4-{[6-({(2R)-2-hydroxy-2-[4-hydroxy-3-(hydroxy-methyl)phenyl]ethyl}amino)-hexyl]oxy}butyl)benzenesulfonamide; GSK 159797, GSK 159802, GSK 597901, GSK 642444, GSK 678007; and a compound selected from *N*-[2-(Diethylamino)ethyl]-*N*-(2-{[2-(4-hydroxy-2-oxo-2,3-dihydro-1,3-benzothiazol-7-yl)ethyl]amino}ethyl)-3-[2-(1-naphthyl)ethoxy]propanamide, *N*-[2-(Diethylamino)ethyl]-*N*-(2-{[2-(4-hydroxy-2-oxo-2,3-dihydro-1,3-benzothiazol-7-yl)ethyl]amino}ethyl)-3-[2-(3-chlorophenyl)ethoxy]propanamide, 7-[(1*R*)-2-({2-[(3-{[2-(2-Chlorophenyl)ethyl]amino}propyl)thio]ethyl}amino)-1-hydroxyethyl]-4-hydroxy-1,3-benzothiazol-2(3*H*)-one, and *N*-Cyclohexyl-N^3-[2-(3-fluorophenyl)ethyl]-*N*-(2-{[2-(4-hydroxy-2-oxo-2,3-dihydro-1,3-benzothiazol-7-yl)ethyl]amino}ethyl)-β-alaninamide or a pharmaceutically acceptable salt thereof (e.g. wherein the counter ion is hydrochloride (for example a monohydrochloride or a dihydrochloride), hydrobromide (for example a monohydrobromide or a dihydrobromide), fumarate, methanesulphonate, ethanesulphonate, benzenesulphonate, 2,5-

dichlorobenzenesulphonate, *p*-toluenesulphonate, napadisylate (naphthalene-1,5-disulfonate or naphthalene-1-(sulfonic acid)-5-sulfonate), edisylate (ethane-1,2-disulfonate or ethane-1-(sulfonic acid)-2-sulfonate), D-mandelate, L-mandelate, cinnamate or benzoate.)

(xii) Muscarinic antagonists:- Aclidinium bromide, Glycopyrrolate (such as R,R-, R,S-, S,R-, or S,S-glycopyrronium bromide), Oxitropium bromide, Pirenzepine, telenzepine, Tiotropium bromide, 3(R)-1-phenethyl-3-(9H-xanthene-9-carbonyloxy)-1-azoniabicyclo[2.2.2]octane bromide, (3R)-3-[(2S)-2-cyclopentyl-2-hydroxy-2-thien-2-ylacetoxy]-1-(2-phenoxyethyl)-1-azoniabicyclo[2.2.2]actane bromide, a quaternary salt (such as [2-((R)-Cyclohexyl-hydroxy-phenyl-methyl)-oxazol-5-ylmethyl]-dimethyl-(3-phenoxy-propyl)-ammonium salt, [2-(4-Chloro-benzyloxy)-ethyl]-[2-((R)-cyclohexyl-hydroxy-phenyl-methyl)-oxazol-5-ylmethyl]- dimethyl-ammonium salt and (*R*)-1-[2-(4-Fluoro-phenyl)-ethyl]-3-((*S*)-2-phenyl-2-piperidin-1-yl-propionyloxy)-1-azonia-bicyclo[2.2.2]octane salt wherein the counter-ion is, for example, chloride, bromide, sulfate, methanesulfonate, benzenesulfonate (besylate), toluenesulfonate (tosylate), napthalenebissulfonate (napadisylate or hemi-napadisylate), phosphate, acetate, citrate, lactate, tartrate, mesylate, maleate, fumarate or succinate)

(xiii) p38 Inhibitors:- 681323, 856553, AMG548 (2-[[(2S)-2-amino-3-phenylpropyl]amino]-3-methyl-5-(2-naphthalenyl)-6-(4-pyridinyl)-4(3H)-pyrimidinone), Array-797, AZD6703, Doramapimod, KC-706, PH 797804, R1503, SC-80036, SCIO469, 6-chloro-5-[[(2*S*,5*R*)-4-[(4-fluorophenyl)methyl]-2,5-domethyl-1-piperazinyl]carbonyl]-*N*,*N*,1-trimethyl- -oxo-1*H*-indole-3-acetamide, VX702 and VX745 (5-(2,6-dichlorophenyl)-2-(phenylthio)-6H-pyrimido[1,6-b]pyridazin-6-one);

(xiv) PDE Inhibitors:- 256066, Arofylline (3-(4-chlorophenyl)-3,7-dihydro-1-propyl-1H-Purine-2,6-dione), AWD 12-281 (N-(3,5-dichloro-4-pyridinyl)-1-[(4-fluorophenyl)methyl]-5-hydroxy-α-oxo-1H-indole-3-acetamide), BAY19-8004 (Bayer), CDC-801 (Calgene), Celgene compound ((βR)-β-(3,4-dimethoxyphenyl)-1,3-dihydro-1-oxo-2H-isoindole-2-propanamide), Cilomilast (cis-4-cyano-4-[3-(cyclopentyloxy)-4-methoxyphenyl]-cyclohexanecarboxylic acid), 2-(3,5-dichloro-4-pyridinyl)-1-(7-

methoxyspiro[1,3-benzodioxole-2,1'-cyclopentan]-4-yl)ethanone (CAS number 185406-34-2)), (2-(3,4-difluorophenoxy)-5-fluoro-N-[cis-4-[(2-hydroxy-5-methylbenzoyl)amino]cyclohexyl]-)-3-pyridinecarboxamide), (2-(3,4-difluorophenoxy)-5-fluoro-N-[cis-4-[[2-hydroxy-5-(hydroxymethyl)benzoyl]amino]cyclohexyl]-3-pyridinecarboxamide,), CT2820, GPD-1116, Ibudilast, IC 485, KF 31334, KW-4490, Lirimilast ([2-(2,4-dichlorobenzoyl)-6-[(methylsulfonyl)oxy]-3-benzofuranyl])-urea), (N-cyclopropyl-1,4-dihydro-4-oxo-1-[3-(3-pyridinylethynyl)phenyl]-)-1,8-naphthyridine-3-carboxamide), (N-(3,5-dichloro-4-pyridinyl)-4-(difluoromethoxy)-8-[(methylsulfonyl)amino])-1-dibenzofurancarboxamide), ONO6126, ORG 20241 (4-(3,4-dimethoxyphenyl)-N-hydroxy-)-2-thiazolecarboximidamide), PD189659/PD168787 (Parke-Davis), Pentoxifylline (3,7-dihydro-3,7-dimethyl-1-(5-oxohexyl)-)-1H-purine-2,6-dione), compound (5-fluoro-N-[4-[(2-hydroxy-4-methyl-benzoyl)amino]cyclohexyl]-2-(thian-4-yloxy)pyridine-3-carboxamide), Piclamilast (3-(cyclopentyloxy)-N-(3,5-dichloro-4-pyridinyl)-4-methoxy-benzamide), PLX-369 (WO 2006026754), Roflumilast (3-(cyclopropylmethoxy)-N-(3,5-dichloro-4-pyridinyl)-4-(difluoromethoxy)benzamide), SCH 351591 (N-(3,5-dichloro-1-oxido-4-pyridinyl)-8-methoxy-2-(trifluoromethyl)-5-quinolinecarboxamide), SelCID(TM) CC-10004 (Calgene), T-440 (Tanabe), Tetomilast (6-[2-(3,4-diethoxyphenyl)-4-thiazolyl]-2-pyridinecarboxylic acid), Tofimilast (9-cyclopentyl-7-ethyl-6,9-dihydro-3-(2-thienyl)-5H-pyrazolo[3,4-c]-1,2,4-triazolo[4,3-a]pyridine), TPI 1100, UCB 101333-3 (N,2-dicyclopropyl-6-(hexahydro-1H-azepin-1-yl)-5-methyl-4-pyrimidinamine), V-11294A (Napp), VM554/VM565 (Vernalis), and Zardaverine (6-[4-(difluoromethoxy)-3-methoxyphenyl]-3(2H)-pyridazinone).

(xv) PDE5 Inhibitors:- Gamma-glutamyl[s-(2-iodobenzyl)cysteinyl]glycine, Tadalafil, Vardenafil, sildenafil, 4-phenyl-methylamino-6-chloro-2-(1-imidazolyl)-quinazoline, 4-phenyl-methylamino-6-chloro-2-(3-pyridyl)-quinazoline, 1,3-dimethyl-6-(2-propoxy-5-methanesulphonylamidophenyl)-1,5-dihydropyrazolo[3,4-d]pyrimidin-4-

one and 1-cyclopentyl-3-ethyl-6-(3-ethoxy-4-pyridyl)-pyrazolo[3,4-d]pyrimidin-4-one;

(xvi) PPARγ agonists:- Pioglitazone, Pioglitazone hydrochloride, Rosiglitazone Maleate, Rosiglitazone Maleate ((-)-enantiomer, free base), Rosiglitazone maleate/Metformin hydrochloride and Tesaglitizar;

(xvii) Protease Inhibitors:- Alpha1-antitrypsin proteinase Inhibitor, EPI-HNE4, UT-77, ZD-0892, DPC-333, Sch-709156 and Doxycycline;

(xviii) Statins:- Atorvastatin, Lovastatin, Pravastatin, Rosuvastatin and Simvastatin

(xix) Thromboxane Antagonists: Ramatroban and Seratrodast;

(xx) Vasodilators:- A-306552, Ambrisentan, Avosentan, BMS-248360, BMS-346567, BMS-465149, BMS-509701, Bosentan, BSF-302146 (Ambrisentan), Calcitonin Gene-related Peptide, Daglutril, Darusentan, Fandosentan potassium, Fasudil, Iloprost, KC-12615 (Daglutril), KC-12792 2AB (Daglutril) , Liposomal treprostinil, PS-433540, Sitaxsentan sodium, Sodium Ferulate, TBC-11241 (Sitaxsentan), TBC-3214 (N-(2-acetyl-4,6-dimethylphenyl)-3-[[(4-chloro-3-methyl-5-isoxazolyl)amino]sulfonyl]-2-thiophenecarboxamide), TBC-3711, Trapidil, Treprostinil diethanolamine and Treprostinil sodium;

(xxi) ENACs:- Amiloride, Benzamil, Triamterene, 552-02, PSA14984, PSA25569, PSA23682 and AER002.

The medicament powder may contain a combination of two or more active ingredients, for example a combination of two or more of the specific active ingredients listed in (i) to (xxi) herein above.

In one embodiment the medicament powder contains an active ingredient selected from mometasone, ipratropium bromide, tiotropium and salts thereof, salemeterol, fluticasone propionate, beclomethasone dipropionate, reproterol, clenbuterol, rofleponide and salts, nedocromil, sodium cromoglycate, flunisolide, budesonide, formoterol fumarate dihydrate, terbutaline, terbutaline sulphate, salbutamol base and sulphate, fenoterol, 3-[2-(4-Hydroxy-2-oxo-3H-1,3-benzothiazol-7-yl)ethylamino]-N-[2-[2-(4-methylphenyl)ethoxy]ethyl]propane-sulphonamide, hydrochloride, indacaterol, aclidinium bromide, *N*-[2-(Diethylamino)ethyl]-*N*-(2-{[2-(4-hydroxy-2-

oxo-2,3-dihydro-1,3-benzothiazol-7-yl)ethyl]amino}ethyl)-3-[2-(1-naphthyl)ethoxy]propanamide or a pharmaceutically acceptable salt thereof (e.g. dihydrobromide); *N*-Cyclohexyl-N^3-[2-(3-fluorophenyl)ethyl]-*N*-(2-{[2-(4-hydroxy-2-oxo-2,3-dihydro-1,3-benzothiazol-7-yl)ethyl]amino}ethyl)-β-alaninamide or a pharmaceutically acceptable salt thereof (e.g. di-D-mandelate); a [2-(4-Chloro-benzyloxy)-ethyl]-[2-((R)-cyclohexyl-hydroxy-phenyl-methyl)-oxazol-5-ylmethyl]-dimethyl-ammonium salt (e.g. hemi-naphthalene-1,5-disulfonate); a (*R*)-1-[2-(4-Fluoro-phenyl)-ethyl]-3-((*S*)-2-phenyl-2-piperidin-1-yl-propionyloxy)-1-azonia-bicyclo[2.2.2]octane salt (e.g. bromide or toluenesulfonate); or a combination of any two or more thereof.

Specific combinations of active ingredients which may be incorporated in the medicament powder include:-

(a) formoterol (e.g. as fumarate) and budesonide;

(b) formoterol (e.g. as fumarate) and fluticasone;

(c) *N*-[2-(Diethylamino)ethyl]-*N*-(2-{[2-(4-hydroxy-2-oxo-2,3-dihydro-1,3-benzothiazol-7-yl)ethyl]amino}ethyl)-3-[2-(1-naphthyl)ethoxy]propanamide or a pharmaceutically acceptable salt thereof (e.g. dihydrobromide) and a [2-(4-Chloro-benzyloxy)-ethyl]-[2-((R)-cyclohexyl-hydroxy-phenyl-methyl)-oxazol-5-ylmethyl]- dimethyl-ammonium salt (e.g. hemi-naphthalene-1,5-disulfonate);

(d) *N*-[2-(Diethylamino)ethyl]-*N*-(2-{[2-(4-hydroxy-2-oxo-2,3-dihydro-1,3-benzothiazol-7-yl)ethyl]amino}ethyl)-3-[2-(1-naphthyl)ethoxy]propanamide or a pharmaceutically acceptable salt thereof (e.g. dihydrobromide) and a (*R*)-1-[2-(4-Fluoro-phenyl)-ethyl]-3-((*S*)-2-phenyl-2-piperidin-1-yl-propionyloxy)-1-azonia-bicyclo[2.2.2]octane salt (e.g. bromide or toluenesulfonate);

(e) *N*-Cyclohexyl-N^3-[2-(3-fluorophenyl)ethyl]-*N*-(2-{[2-(4-hydroxy-2-oxo-2,3-dihydro-1,3-benzothiazol-7-yl)ethyl]amino}ethyl)-β-alaninamide or a pharmaceutically acceptable salt thereof (e.g. di-D-mandelate) and [2-(4-Chloro-benzyloxy)-ethyl]-[2-((R)-cyclohexyl-hydroxy-phenyl-methyl)-oxazol-5-ylmethyl]- dimethyl-ammonium salt (e.g. hemi-naphthalene-1,5-disulfonate);

(f) *N*-Cyclohexyl-N^3-[2-(3-fluorophenyl)ethyl]-*N*-(2-{[2-(4-hydroxy-2-oxo-2,3-dihydro-1,3-benzothiazol-7-yl)ethyl]amino}ethyl)-β-alaninamide or a

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pharmaceutically acceptable salt thereof (e.g. di-D-mandelate) and a (*R*)-1-[2-(4-Fluoro-phenyl)-ethyl]-3-((*S*)-2-phenyl-2-piperidin-1-yl-propionyloxy)-1-azonia-bicyclo[2.2.2]octane salt (e.g. bromide or toluenesulfonate).

It is preferred that the medicament powder is formulated as an ordered mixture, with fine powder active ingredient particles adhered to larger carrier particles of e.g. lactose.

According to another aspect of the invention, there is provided a method for dispensing an air stream carrying a dose of medicament powder comprising passing a flow of air across the opening of a powder-containing cavity having, the length of the cavity opening in the flow direction being (i) between 50% and 150% of the cavity depth, and (ii) at least 80% of the maximum length of the cavity in the flow direction, wherein the velocity of the flow immediately adjacent the cavity opening is at least 15m/s, and wherein the lower front and/or rear edges of the cavity, with respect to the flow direction, have a radius of between 0.5 and 3mm, preferably between 1.5 and 2.5mm, more preferably between 1.75mm and 2.25mm.

The inventors believe that by generating a flow of this velocity across the opening of the cavity, a rotating flow in the cavity may be created which will give rise to effective emptying and deaggregation. There may, of course, be a variation of flow across the cross section of the passage.

Preferably, the mass of residual active pharmaceutical ingredient (API) in the cavity after dispensing amounts to between 0.1% and 10% by mass of the total mass of API in the cavity prior to dispensing, preferably between 1% and 8%, more preferably between 1% and 5%. It is normal to measure retention by the mass of API rather than the total powder mass. The term "medicament powder" is used in this specification to mean the complete powder formulation, including API, carrier particles and any other ingredients.

The device is intended to be a platform for delivery of a wide range of powder formulations. The specific powder is therefore not relevant to the invention. The device has been tested with a number of standard and experimental formulations. Since some of these formulations are under development at the time of filing this

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application and the composition of the formulations is commercially sensitive confidential information, this information is not included in this application. However, the inventors believe, based on work which is set out in detail in Example 6 below, that surface shear stress in flow modeled by computational fluid dynamics techniques, in particular the average surface shear stress in the lower half of the cavity (based on half the perpendicular distance from the plane of the cavity opening to the deepest extent of the cavity), gives a good measure of the empting of the cavity. Although emptying will vary between different formulations, the inventors believe that, for a given formulation, higher surface shear stress in the lower half of the cavity would normally result in more efficient emptying.

According to an alternative embodiment of the invention, a method for dispensing an air stream carrying a dose of medicament powder comprises passing a flow of air across the opening of a powder-containing cavity, the length of the cavity opening in the flow direction being (i) between 50% and 150% of the cavity depth, and (ii) at least 80% of the maximum length of the cavity in the flow direction, the average surface shear stress over the lower half of the cavity being at least 0.5Pa, preferably at least 1Pa, more preferably at least 1.5Pa, the upper end of these ranges being 20Pa or preferably 15Pa. This is based computer modeling of the flow in the cavity, with Reynolds averaged Navier-Stokes (RAND), turbulent, three dimensional, steady computational fluid dynamics (CFD) calculations using the ANSYS® software Fluent, version 6.3.26.

In another embodiment, the invention comprises a method for dispensing an air stream carrying a dose of medicament powder comprises passing a flow of air across the opening of a powder-containing cavity having only a single opening, the length of the cavity opening in the flow direction being between 50% and 150% of the cavity depth, characterized in that the maximum velocity of the flow immediately adjacent the cavity opening is at least 15m/s, preferably at least 20m/s, more preferably at least 30m/s, more preferably at least 40m/s or as much as 50m/s. The flow may preferably be in the range 15m/s to 100m/s, more preferably 20m/s to 80m/s.

According to an alternative embodiment of the invention, a method for dispensing an air stream carrying a dose of medicament powder comprises passing a flow of air

across the opening of a powder-containing cavity having only a single opening, the cavity opening having length in the flow direction of between 50% and 150% of the cavity depth, the average surface shear stress over the lower half of the cavity being at least 0.5Pa, preferably at least 1Pa, more preferably at least 1.5Pa, the upper end of these ranges being 20Pa or preferably 15Pa. This is based computer modeling of the flow in the cavity, with Reynolds averaged Navier-Stokes (RAND), turbulent, three dimensional, steady computational fluid dynamics (CFD) calculations using the ANSYS® software Fluent, version 6.3.26.

There are also a number of other parameters of the flow in the cavity which it is possible to calculate using the computational fluid dynamics technique referred to above. The inventors are not certain which of these parameters give the best indication of cavity emptying efficiency. The parameters referred to below are also derived from a computer model with RAND, turbulent, three dimensional, steady CFD calculations using the ANSYS® software Fluent, version 6.3.26.

Thus, according to another embodiment of the invention, a method for dispensing an air stream carrying a dose of medicament powder comprises passing a flow of air across the opening of a powder-containing cavity, the length of the cavity opening in the flow direction being (i) between 50% and 150% of the cavity depth, and (ii) at least 80% of the maximum length of the cavity in the flow direction, the average turbulent kinetic energy in the lower half of the cavity being at least 3 m^2/s^2, preferably at least 4 m^2/s^2, more preferably at least 5 m^2/s^2. The upper end of these ranges may be 50 m^2/s^2, preferably 20m^2/s^2.

According to another embodiment of the invention, a method for dispensing an air stream carrying a dose of medicament powder comprises passing a flow of air across the opening of a powder-containing cavity, the length of the cavity opening in the flow direction being (i) between 50% and 150% of the cavity depth, and (ii) at least 80% of the maximum length of the cavity in the flow direction, the average vorticity in the lower half of the cavity being at least 2,000 1/s preferably at least 4,000 1/s, more preferably at least 10,000 1/s. The upper end of these ranges may be 100,000 1/s, preferably 50,0001/s, more preferably 20,000 1/s.

According to another embodiment of the invention, a method for dispensing an air stream carrying a dose of medicament powder comprises passing a flow of air across the opening of a powder-containing cavity, the length of the cavity opening in the flow direction being (i) between 50% and 150% of the cavity depth, and (ii) at least 80% of the maximum length of the cavity in the flow direction, the average flow velocity in the lower half of the cavity being at least 1.5m/s, preferably at least 3m/s, more preferably at least 4m/s. The upper end to these ranges may be 30m/s, preferably 20m/s, more preferably 10m/s.

According to another embodiment of the invention, a method for dispensing an air stream carrying a dose of medicament powder comprises passing a flow of air across the opening of a powder-containing cavity having only a single opening, the cavity opening having length in the flow direction of between 50% and 150% of the cavity depth, the average turbulent kinetic energy in the lower half of the cavity being at least 3 m^2/s^2, preferably at least 4 m^2/s^2, more preferably at least 5 m^2/s^2. The upper end of these ranges is 50 m^2/s^2, preferably 20m^2/s^2.

According to another embodiment of the invention, a method for dispensing an air stream carrying a dose of medicament powder comprises passing a flow of air across the opening of a powder-containing cavity having only a single opening, the cavity opening having length in the flow direction of between 50% and 150% of the cavity depth, the average vorticity in the lower half of the cavity being at least 2,000 1/s preferably at least 4,000 1/s, more preferably at least 10,000 1/s. The upper end of these ranges may be 100,000 1/s, preferably 50,000 1/s, more preferably 20,000 1/s.

According to another embodiment of the invention, a method for dispensing an air stream carrying a dose of medicament powder comprises passing a flow of air across the opening of a powder-containing cavity having only a single opening, the cavity opening having length in the flow direction of between 50% and 150% of the cavity depth, the average flow velocity in the lower half of the cavity being at least 1.5m/s, preferably at least 3m/s, more preferably at least 4m/s. The upper end to these ranges may be 30m/s, preferably 20m/s, more preferably 10m/s.

Flow in the cavity as defined in any of the paragraphs above is preferably created solely by the phenomenon of shear driven cavity flow.

Preferably, in a method as defined above, the medicament powder comprises a compound or combination selected from the list which appears above.

Definitions:

The aspect ratio of the cavity opening is defined as the perpendicular length (in the case of a trapezoidal shape being the length of the line of symmetry) of the opening divided by the mean width.

The term "height", referring to the flow passage shall mean the perpendicular distance from the wall of the passage in which the cavity opening is formed to the opposite wall of the passage.

The term "width", referring to the flow passage, at any given location in the flow passage, shall mean the shortest distance between the two side walls at that location.

The term "floor" shall mean the wall of the flow passage in which the cavity opening is formed. The term "ceiling" shall mean the wall of the flow passage opposite the floor.

The term "side wall" in relation to the flow passage shall mean a flow passage wall which extends between the floor and the ceiling.

The plane of the cavity opening shall mean the plane defined by the rim of the cavity, the rim being the interface between the cavity and the flow passage. If the rim does not lie completely in one plane, then the plane of the cavity opening shall mean the plane which is the best fit to the rim.

The term "quadrilateral" shall mean a shape having four straight edges, but the term shall not exclude the corners having fillet radii as specified herein.

The term "depth" in connection with the cavity shall mean the perpendicular distance from the plane of the cavity opening to the deepest point of the cavity.

The maximum length of the cavity shall be defined as the greatest length of the cavity in the flow direction, measured in a plane parallel to the plane of the cavity opening

Where expressions such as "up" and "down" are used with respect to a device in this specification, it is assumed that the orientation of the device is such that the opening of the cavity or cavities faces upwards.

The term "medicament powder" shall mean all of a powder formulation, including without limitation any carrier, diluent or coating in addition to any active pharmaceutical ingredients.

Brief Description of the Drawings

The present invention will now be described, for exemplary purposes, in more detail by way of embodiments and examples and with reference to the enclosed drawings, in which:

Fig. 1 is a schematic cross sectional view of a flow passage region of a first embodiment;
Fig. 2 is a schematic cross sectional view of a flow passage region of a second embodiment;
Figs. 3a-3d are schematic perspective views of part of the flow passage region of Figure 1, showing a sequence of operation;
Fig. 4 is a plan view of the entire first embodiment;
Fig. 5 is an exploded perspective view of a cavity disc and support of the first embodiment;
Fig. 6 is a side sectional view of part of a third embodiment, showing the cavity disc and two cavities;
Figure 7 is a perspective view of a computer model of the flow path of the inhaler of US4,446,862, used in Example 1;
Figure 8 is a side view of the computer flow path model of Figure 7;

Figure 9 is a perspective view of a computer model of the flow path of an inhaler according to the invention, used in Example 2;
Figure 10 is a graph showing the results of computer modeling of powder entrainment in the flow path of Figures 7 and 8 and also in a flow path in accordance with the invention;
Figure 11a is a side view of a computer model of a flow path in accordance with the invention;
Figure 11b is a plan view of the cavity shown in Figure 11a;
Figure 12 is a bar chart showing powder retention for four different shapes of cavity;
Figure 13 is a graph showing the degree of powder retention for two alternative designs of cavity and for nine different powder formulations;
Figures 14a and 14b are side and perspective views, respectively, of an alternative flow path model of a device according to the invention;
Figures 15a and 15b are side and perspective views, respectively, of an alternative flow path model of a device with increases channel height; and
Figure 16 is a perspective view of the cavity disc of a modification of the third embodiment.

Example 1 (prior art)

Figures 7 and 8 show a computer model of the flow path of the device described in US4,446,862 (referred to above). This model is based on the main embodiment described in this prior patent (Figures 1 to 4a). The device comprises a flat cylindrical flow chamber 101, in the base of which is located a separated part 102 of a standard size 4 pharmaceutical capsule containing a powder for inhalation. Evenly spaced around half of the circumference of the chamber and located towards the lower end are six air inlets 103. Symmetrically opposite the inlets 103 is a mouthpiece 104 of rather larger diameter than the inlets 103.

Some dimensions are specified in US4,446,862. For example the inlet diameter is said to be 2mm – see col. 6, line 19, and the use of standard size 4 capsules is specified in col. 7, line 15. Size 4 capsules have a capsule base inner diameter of approximately 5mm and a capsule base length of approximately 7mm. The remaining

dimensions have been taken from Figure 4a, scaled according to the values which are specified in the text.

The model was used to simulate flow in the device using computational fluid dynamics techniques, specifically Reynolds averaged Navier-Stokes (RANS), turbulent, three-dimensional, steady computational fluid dynamics (CFD) using the ANSYS® software Fluent®, version 6.3.26.

In US4,446,862, the pressure drop across the device is said to be 4.7cm H_2O (about 0.46kPa) to produce a flow rate of 28.3l/min. In the CFD simulation, this pressure drop produced a flow rate of 21.9l/min, which represents a fairly good correlation of simulated result to the result reported in US4,446,862. To get a flow rate nearer the target rate according to US4,446,862, a pressure drop of 0.76kPa was needed in the model.

The current standard pressure difference for testing inhaler designs is 4kPa – this is what a normal patient will tend to generate. A weak patient may generate about 2kPa, whilst a very fit one will generate about 6kPa.

The table below shows four sets of results for different pressures and corresponding volume flow rates. 4kPa pressure has been used since it is a modern day standard test condition. 0.46kPa and 0.76kPa have been used for reasons discussed above, and 0.17kPa has been used for reasons which will be explained below in the discussion of Example 2. A number of parameters were computed for each case, labeled 1-8 in Table 1 below, as follows:

Parameter 1: Average shear stress at the cavity surface (Pa) over the whole cavity;
Parameter 2: Average shear stress at the cavity surface (Pa) over lower half of cavity;
Parameter 3: Average flow velocity (ms^{-1}) over the whole cavity;
Parameter 4: Average flow velocity (ms^{-1}) over lower half of cavity;
Parameter 5: Average vorticity (1/s) over the whole cavity;
Parameter 6 Average vorticity (1/s) over lower half of cavity;
Parameter 7: Average turbulent kinetic energy (m^2/s^2) over the whole cavity; and

Parameter 8: Average turbulent kinetic energy (m^2/s^2) over lower half of cavity.

The average surface shear stress at the wall of the cavity, for the lower half of the cavity (based on half the perpendicular distance from the plane of the cavity opening to the bottom of the cavity), is considered by the inventors to represent the best indicator of emptying efficiency for this model. The wall shear stress is defined as:

$$_{w} \quad \frac{v}{n}$$

where

is the molecular viscosity and $\frac{v}{n}$ the normal velocity gradient at the wall.

In Table 1, ΔP is the pressure difference in kPa and Q is the volume flow rate in l/min.

Table 1

		PARAMETER							
P (kPa)	Q (l/min)	1	2	3	4	5	6	7	8
4.00	66.53	1.72	0.43	2.73	1.18	5000	1800	32.00	3.10
0.46	21.90	0.28	0.06	0.39	0.85	1637	592	2.49	0.26
0.17	12.96	0.10	0.02	0.45	0.19	876	288	0.69	0.06
0.76	28.58	0.45	0.08	1.11	0.49	2133	724	4.70	0.45

Example 2 - CFD modeling of devices according to the invention

A computer model of a device according to the invention was created using the same software that was used in Example 1. The entire inhaler device has more automated functions and is more complex than the device described in US4,446,862. There are also two flow paths in the inhaler, one which passes over the powder cavity and a bypass passage. The flow path which passes over the cavity is slightly more tortuous than that of the prior art and there may be a moderately significant pressure drop before the flow passage reaches the cavity. For example, there may be a pressure drop in normal use of between 0.01 and 2.0kPa over the portion of the total flow path

leading up to the cavity. This is preferably at the lower end of that range, e.g. 0.1 to 1.0kPa.

For these reasons, a straight comparison based on overall pressures and volume flows, etc, between the two inhalers is not really the best test. Nonetheless, the whole inhaler was analysed at 4kPa pressure difference between air inlet and mouthpiece, with the results shown in row 1 of Table 2 below. The remaining results in Table 2 are for a section of the flow path which corresponds better with the very simple flow path of the device described in US4,446,862.

The modeled flow path is shown in Figure 9. This path accurately represents the critical part of the flow as regards emptying of the powder cavity. The cavity is shown at 41 and the flow passage over the cavity at 42. The dimensions of the cavity are given in Table 3 below under column "A". The flow passage adjacent the cavity has height 1.5mm and the width is 3.1mm at the upstream end and 5.1mm at the downstream end, with respect to the flow direction F. Part 43 of the floor of the flow passage 42 on the upstream side of the cavity is sloping. Projecting from this floor is a turbulence-inducing obstruction or projection 44 - a so-called "turbulator". The purpose of this feature is to promote turbulence in the flow in the passage 42 which is then imparted to the shear driven flow in the cavity 41. In this example, results were obtained both with and without a turbulator 44 in the flow path; this is indicated in the Table.

The same eight parameters used in Example 1 were computed for the device according to the invention, and the numbered columns in Table 2 below correspond to those of Table 1.

Four of the eight results are parameters average over the whole cavity, whilst the other four are averaged over only the lower half of the cavity. The line 45 half way down the cavity in Figure 9 shows the division between the upper and lower halves of the cavity: it is located at half the perpendicular distance from the plane of the cavity opening to the bottom of the cavity.

The first row of results is for a standard pressure drop of 4kPa over a computer model of the entire inhaler. Approximately 1kPa of this pressure drop was "lost" over other parts of the inhaler model. For the first row results, therefore, the pressure drop across the flow path shown in Figure 9 may be assumed to be approximately 3kPa. The model used for the row 1 results includes a bypass passage, which means that the volume flow rate is very high in comparison with the other results which are for the short section of flow path shown in Figure 9. The volume flow rate through the Figure 9 flow passage only is shown in brackets.

The remaining results are for a given pressure drop across only the flow path of Figure 9. This section of flow path was chosen to be as fair a comparison to the US4,446,862 device as possible. In three of these cases, the turbulator is included in the flow path. In one case, the turbulator was omitted.

Table 2

			PARAMETER							
	P (kPa)	Q (l/min)	1	2	3	4	5	6	7	8
Whole inhaler - no turbulator	4.00	57.50 (12.1)	3.46	2.00	5.14	4.44	15800	10400	9.67	5.96
With turbulator	1.50	12.26	4.17	1.87	5.38	4.36	17661	11012	10.23	5.19
Without turbulator	1.50	12.86	3.57	1.65	4.73	3.98	15563	10498	8.05	4.58
With turbulator	0.46	6.16	1.26	0.37	2.43	1.63	8108	4106	3.08	1.11
With turbulator	7.00	29.70	19.77	14.10	15.51	15.09	49053	39056	45.96	32.49

In Table 1, ΔP is the pressure difference in kPa and Q is the volume flow rate in l/min.

Comparing the results, it is immediately apparent that a much more energetic flow is induced in the cavity in the device according to the invention than in the cavity of US4,446,862. In line four of Tables 1 & 2, the 0.46kPa pressure drop specified in US4,446,862 is applied. The average surface shear stress (Parameter 2) in the lower half of the cavity is 0.37Pa in the device according to the invention and only 0.06Pa in the device according to US4,446,862. This difference is more than a factor of 6 in a

parameter which, as discussed above, is considered by the inventors to be the best indicator of cavity emptying efficiency.

Comparing row 1 of the respective tables, where in each case a pressure drop of 4kPa was applied across the whole inhaler, the values of Parameter 2 are 3.46Pa and 1.72Pa, respectively, for the inhaler of the invention and the device according to US4,446,862 – a factor of more than 2, despite the fact that pressure losses would have occurred in other parts of the inhaler according to the invention, and much of the flow would have been through the bypass channel.

In row 3 of Table 2, a pressure drop of 1.5kPa is applied across the flow path without the turbulator feature; this results in a flow rate of about 12.9l/min and an average surface shear stress in the lower half of the cavity of 3.57Pa. A similar flow rate in the device of US4,446,862 produces an average surface shear stress in the lower half of the cavity of a mere 0.02Pa.

Example 3

A different CFD modeling technique, RANS turbulent, three-dimensional, transient multiphase CFD using the ANSYS® software CFX®, release 11.0, was employed to model the movement of powder in the airflow in the cavities, specifically to obtain results relating to the emptying of the cavities. The software simulated inter-phase momentum transfer using a dispersed particle model with a particle size of 50micron.

The flow path of Example 2 / Figure 9, without turbulator, was compared to the flow path of Example 1 (the CFD model of the device of US4,446,862). The same flow rate of 12l/min was applied to each flow path and, in the model, the cavity was initially filled with powder to 2/3 of the total cavity volume

The simulation was made for the first 100mS after initiation of airflow. As can be seen from the graph of the results in Figure 10, after 100mS, the cavity in the flow path according to the invention was substantially empty, whilst the cavity of the US4,446,862 device still contained more than 90% of the original mass of powder. More powder may subsequently have been entrained in the air flow in the

US4,446,862 device if the simulation had been extended, but this Example demonstrates at least that the rate of emptying of a cavity in a device or flow path according to the invention appears to be markedly superior to that of US4,446,862. It is generally considered desirable in the inhaler art to entrain powder in as short a time period as possible.

Example 4

Referring to Figures 11a and 11b, a flow path in accordance with the invention is shown. Various dimensions of the cavity were altered in the CFD model referred to in Example 2. These dimensions are shown in Figures 11a and 11b and also in Table 3 below. Fillet radius is shown at 207 in Figure 11b, Rear radius at 203 in Figure 11a, Front (downstream) radius at 204, Length at 201 and depth at 202. Rear half-width is shown at 205 in Figure 11b and Front half-width at 206. The flow passage passing over the cavity is shown at 210 and cavity at 211. The direction of flow is indicated by arrow F. One alternative shape of cavity, with corresponding reference numerals indicating equivalent features of the geometry, is shown in Figures 11c and 11d. Six designs were tested in total.

Analysis was performed using the same software as in Examples 1 and 2. The model included a turbulator (reference 212 in Figure 11a). For each geometry, the average surface shear stress over the lower half of the cavity was computed. The results are shown in Table 3 below.

Table 3

Cavity design	**A**	**B**	**C**	**D**	**E**	**F**
Fillet Radius [mm]	0.3	0.2	0.22	0.2	0.2	0.201
Rear Radius (lower upstream edge) [mm]	2	2.2	2.09	2.16	2.14	2.17
Front Radius (lower downstream edge) [mm]	1	2.2	1.8	2.1	2.06	1.8
Length in flow direction [mm]	4.5	5.5	4.95	5.43	5.5	5.19
Depth [mm]	4.5	4.2	4.58	4.95	5.5	4.46
Length/depth	1.00	1.31	1.08	1.10	1.00	1.16

Rear Half Width [mm]	0.958	0.8	1.03	1.1	1.3	1.1
Front Half Width [mm]	1.35	1.1	0.7	0.67	0.65	0.72
Area Cavity [mm2]	58.3	57.6	56.9	67.1	79	59
Area Lower Half of Cavity [mm2]	30.4	29.4	28.9	34.3	40.6	30.1
Volume Cavity [mm3]	39.13	35.3	32.8	40.5	51.4	35.5
Shear stress Lower Half of Cavity [Pa]	**2.08**	**3.46**	**4.16**	**4.34**	**4.32**	**4.6**

It can be seen from the results that changing the cavity shape can have a significant effect on the average shear stress. Design A is shown in Figures 11a and 11b. This is also the design shown in Figure 9 . This design had been developed using high speed imaging of powder flow in physical models of cavities - it had been determined that this shape produced considerably better emptying of the cavity than a simple cuboid shape of approximately equivalent overall proportions (length, depth, width). However, the CFD results shown in Table 3 unexpectedly show that considerably better performance is possible by refining the geometry further.

Changing Design A to increase the aspect ratio in plan view – that is to say increasing the length relative to the width – appeared to result in substantially greater surface shear stress in the lower half of the cavity. Furthermore, increasing the size of the front radius (that is to say, the downstream radius) appeared to have a marked effect. These changes can be seen, for example, in Design B which is shown in Figures 11c and 11d.

The work of optimising the cavity shape is ongoing but at present it is believed that the best geometry will involve both front and rear radii of between 1.75mm and 2.25mm.

Example 5

Physical prototypes of Designs A, B C and F in Example 4 were created using rapid prototyping techniques. These models were then tested using by filling them with two different powder formulations, one very challenging and the other less so. A pressure of 1.5kPa was applied to each design to generate airflow through the prototypes equivalent to a very weak human patient inhaling. Figures for emptying expressed as

the percentage mass of active pharmaceutical ingredient (API) remaining the cavity were determined for each design.

The results are shown in Figure 12. The shaded columns represent results for the more challenging formulation, whilst the plain columns represent the less challenging formulation. A marked reduction in retention of API powder can be seen between Design A and Design B, consistent with the CFD results in Table 3. However, an increase in retention is seen from Design B to Design C, despite the fact that the average surface shear stress value in the CFD work for Design C was higher than for Design B. Design F showed retention broadly similar to Design B, although the surface shear stress from the CFD work was higher.

The inventors believe that the physical prototypes for Designs C and F, particularly for Design C, were badly made and that this is the main reason for the increased retention compared with Design B. From Table 3 it will be seen that Designs C and F (and in fact also Designs D and E) have a "reverse taper" – their upstream end is wider than their downstream end – and this shape is not suited to the current multi-dose inhaler design (see the description of the third embodiment below). For this reason, work with Designs C to F has been stopped for the present at least and attention has been focused on Design B. It is still the inventors' view, however, that if properly manufactured and filled, Designs C to F would have lower powder retention than Design B. These "reverse taper" designs (C to F) may also be useful in an inhaler of a different design.

Example 6

Similar testing to that of Example 5 was performed using the prototypes for Designs A and B, using 9 different standard and experimental powder formulations.

Figure 13 shows a plot of retention of powder in the cavity for Design A and Design B. As can be seen, for every formulation Design B showed less retention of powder.

For both cavity shapes, the pressure drop across the section of flow path was 1.5kPa. The average surface shear stress in the lower half of the cavity for the original design

(calculated in Example 4) was 2.08Pa, whilst the same value for the second shape (from Example 4) was 3.46kPa. The inventors believe that this result supports their hypothesis that average surface shear stress in the lower half of the cavity is correlated to emptying efficiency.

Example 7

A slightly different computer model of the flow path for a device according to the invention was generated for the purpose of assessing the effect of flow passage height on the performance of the device. The models for a 1.5mm channel height and a 10mm channel height are shown in Figures 14a&b and 15a&b respectively. The width of the channel was the same for each model, diverging slightly in the downstream direction and being from 3.1mm at its narrowest to 5.1mm at its widest point. The upstream part 53 of the flow passage 52 was redesigned to have a flat "floor" 54 (ie the wall of the flow path in which the cavity is formed). The reason for this was that it was found that, if the inclined floor was retained, in a model with increased "ceiling" height (i.e. distance 55 from the "floor" to the opposite wall), then the flow was directed upwards and away from the flow passage floor. The inclined upstream passage has relatively little effect when the height of the passage over the cavity is small (e.g. around 1.5mm), but the inventors believe that a fair assessment of the effect of increasing flow passage height could only be made if the passage continued to direct flow across the cavity opening (as opposed to away from it).

A number of different channel heights were modeled, each with a cavity 51 of Design A (see Examples 5 & 6 above).

CFD calculations were made based on a volume flow rate of 25l/min passing down the channel in each case. The average surface shear stress for the lower half of the cavity was calculated for each case, using the same software as used in Examples 1 and 2, with the same definitions applying. The results are shown in Table 4 below.

Table 4

Flow passage height (mm)	Average surface shear stress – lower half of cavity (Pa)
1.5	6.6
3	0.99
5	0.05
10	0.03

As can be seen, the result of increasing the flow passage height is a dramatic reduction in the average surface shear stress in the lower half of the cavity. The inventors believe that this is principally due to the reduced airflow velocity across the cavity.

In the current design, in order to keep tolerances within reasonable limits and have an easily manufacturable device, the flow passage height is 1.5mm. However, should it become necessary to increase further the emptying efficiency of the device then the inventors believe that decreasing the flow passage height still further would easily achieve this. A flow passage height of 1mm or even 0.5mm is contemplated.

Interpolating these results, an average surface shear stress value over the lower half of the cavity for a flow passage height of 4mm would be about 0.5Pa based on a straight line drawn between the 3mm and 5mm values on a graph. This represents a considerable improvement on the surface shear stress values generated by the device of US4,446,862 under equivalent conditions.

Example 8

CFD studies with simple cuboid and capsule shaped cavities were performed and it was found that a cuboid shaped cavity showed more promising results than a capsule shaped cavity. The rate of emptying is found to be slightly slower for a capsule shaped cavity. While the flow in the cuboid shaped cavity is found to be substantially two-dimensional, the flow in the capsule shaped cavity is found to be three-dimensional. The three-dimensional flow in the capsule shaped cavity is found to result in a greater concentration of particles at and near the centerline downstream of the cavity. A major difference is in the capacity to promote a cylindrical flow pattern.

It is believed that the capsule-shaped cavity does not allow the build up of a cylindrical flow pattern.

A number of non-limiting embodiments of the invention will now be described with reference to Figures 1 to 6 and 16.

A first embodiment of the invention is shown schematically in Figure 4. This is a multi-dose inhalation device from which a user may inhale doses of medicament in the form of dry powder. The device 1 includes a housing 23 and a mouthpiece 3. The mouthpiece 3 may be uncovered by linear movement of a mouthpiece cover 24. In a modification of this embodiment (not shown), the mouthpiece cover is pivotally supported by the housing.

The essential parts of the interior of the device 1, as they relate to the present invention, are shown in Figures 1, 3, 4 and 5. Inside the housing 23 is a disc-shaped structure 18 containing a plurality of cavities 5. The cavity disc 18 is rotatably supported in a cavity disc holder 19. The cavities 5 are arranged in an annular pattern around the periphery of the disc. The disc 18 has a large central hole 26 which accommodates other components of the inhaler device including an air inlet channel (not shown) and a mechanism (also not shown) for moving the disc around to expose new cavities for each inhalation. A separate flow channel (not shown) is provided over each cavity 5, with the top surface 25 of the disc 18 forming the lower surface of the channel.

Figure 1 schematically shows a cavity 5 and adjacent flow path 4 of the first embodiment. The height of the flow path is shown at 13. The cavity 5 is cuboid shaped and the cavity opening 20 has a rim 6 where the sides of the cavity 5 meet the flow passage lower wall or "floor" 7. The cavity contains medicament powder 2. It is advantageous that the cavity is shaped to allow a cylindrical airflow pattern within the cavity 5. The cylindrical flow pattern in the cavity is developed around an axis located transverse to the flow direction and approximately in the middle of the cavity. The sides of the cavity are perpendicular to the floor 7.

Now, with reference to Figs. 1 and 3 the overall function of the device 1 will be described in more detail. Part of the flow passage 4 has a flat floor 7 (i.e. the lower wall of the passage when the device is in its normal orientation). The floor 7 includes an opening 20 into the powder-containing cavity 5. The passing of an air stream in the flow direction F along the flow passage and across the opening 20 generates a cylindrical circulating flow in the cavity 5 due to the phenomenon of shear driven cavity flow. The powder particles are agitated in this energetic, somewhat turbulent, circulating flow, and also impact the sides of the cavity. It is believed that both the entrainment of particles in the energetic flow and the impacting of particles against the sides of the cavity 5 contribute to deaggregation, bringing the formulation into a condition ready for inhalation. The inventors believe that the powder particles entrained in the circulating flow will tend to be thrown outwardly (or, more precisely, will tend to move tangentially to the flow), and thus will exit the cavity and become entrained in the airflow in the passage 4.

The cavity 5 and cavity opening 20 each have a length 10 in the flow direction F of the flow passage 4 of 5mm. The cavity depth 22 is also 5mm.

The distance 11 from the top of the cavity 5 (i.e. the plane of the cavity opening) to the top of the leveled powder particle bed in an initial condition is 1 mm. This distance is referred to as the headspace 11 of the cavity. The depth of powder in the cavity is shown at 9.

In side section, the cavity is square; the inner corners of the cavity are essentially sharp, that is to say the lower front (downstream) edge 16 and the lower rear (upstream) edge 17 are sharp. In a modification of the first embodiment (not shown), they may have a radius of about 0.5mm in order to provide some guidance in the rotational movement of the generated circulating flow.

Figures 3a to 3d show schematically the emptying of the cavity 5. Air moves along the passage 4 under the influence of a pressure drop created by a patient inhaling (not shown). For the whole inhaler, this may be between 2 and 6kPa. The pressure drop over the section of passage shown in Figure 3 may be between 0.5kPa and 5kPa.

Fig. 3a shows the initial state of the powder-filled cavity 5. An airflow along the flow passage 4 is initiated in the flow direction F and emptying of the cavity 5 starts. In Fig. 3b some of the powder 2 has left the cavity 5, the build up of a circulating flow in the cavity 5 has begun and it can be seen that the cavity 5 starts to empty at the downstream end. As can be seen in Figure 3c, the powder level is gradually eroded downwardly and in an upstream direction. The time elapsed from the initial state in Figure 3a to the final state in Figure 3d depends partly speed of the flow and the exact powder composition, but a normal time for this embodiment would be about 300ms.

A second embodiment of the invention will now be described with reference to Figure 2. The only aspect which is changed from the first embodiment is the shape of the cavity. Reference numerals in this embodiment are the same as for the first embodiment for equivalent features.

In the second embodiment, the parallel front and rear walls of the cavity 5 are oriented at an acute angle in relation to the vertical direction (normal to the cavity opening). The cavity opening 20 is still aligned with flow passage floor 7 in the flow passage 4 adjacent the cavity 5. It is believed that the inclination of the walls in relation to the flow passage 4 make it more difficult for the particles entrained in the circulating flow in the cavity to escape into the flow passage 4. Hence, the inventors believe, in the second embodiment the degree of deaggregation may be increased, since the time for which the medicament powder 2 is entrained in the energetic circulating flow and subject to wall contact/impact is increased. On the other hand, emptying time may be longer for the second embodiment. In Figure 2 the cavity is shown angled in the direction of flow (arrow F), but in a modification of the second embodiment the cavity could be angled in the opposite direction, that is to say with the angle in Figure 2 having a negative value.

It has been found that powder can be retained by the cavity in the lower upstream and downstream corners/edges. To counteract this, in the second embodiment the lower front (downstream) edge 17 of the cavity 5 has a radius of about 0.5mm, whilst the lower rear (upstream) edge 16 has a radius of approximately 1mm.

A third embodiment of the invention will now be described with reference to Figure 6, which shows a part side section through a multi-dose dry powder inhaler 30. A housing member 31, together with other components (not shown) of an inhaler housing, contain the various components of the inhaler. However, only those components relevant to the present invention are shown in Figure 6.

A cavity disc 32 has a number of powder-containing cavities 33. In use, as with the first embodiment, the disc 32 is rotated in order to bring the individual cavities into registry with a mouthpiece (not shown) located at the edge of the device. Amongst the components not shown in Figure 6 is the mechanism for supporting and advancing the cavity disc.

Associated with each cavity 33 is a lid member 35 which, in an initial state, seals the cavity via a sealing membrane 36. An air inlet 34 is provided in the casing 31 through which air is drawn when a patient inhales through the mouthpiece. Air flows through the device along a path shown by arrows B in Figure 6. An air stream entering the device triggers the lifting of the lid member 35 associated with whichever cavity is in registry with the mouthpiece at that time. The triggering and lid lifting mechanisms are not shown in Figure 6.

The lid member 35 on the left hand side of Figure 6 is shown in the open position. It may be seen that the lid member 35 provides the upper wall, or ceiling, of a flow passage 37 which passes across the top of the now open cavity 33. The lower wall, or floor, of the flow passage is provided by an upper surface of the cavity disc 32. The side walls of the flow passage 37 are provided by the closed lid members 35 on each side of the open member 35. A closed lid member 35 is shown for example on the right side of Figure 6, but it will be appreciated that there are a number of these members 35 all around the circumference of the disc 32. In a modification of this embodiment, the side walls of the flow passages 37 may be provided by separate wall members (not shown) extending between the lid members 35.

As can be seen from the above description, a cavity 33 is opened essentially at the same time that a flow of air passes through the flow passage 37 across the opening of the cavity. A circulating airflow, represented highly schematically at 39, is induced in

the cavity by the phenomenon of shear driven cavity flow. Powder 38 in the cavity is entrained in the circulating flow 39 during which time it is deaggregated, and then the deaggregated powder subsequently entrained in the flow through the flow passage 37 and then through the mouthpiece to the patient.

Each cavity is 4.5mm long in the flow direction, 5mm deep and (in plan view) is tapered in the flow direction, with an average width of 2.3mm. It is filled with powder to a depth of 2.5mm, leaving a 2.5mm headspace. A large radius (2mm) is provided on the upstream lower edge of the cavity to assist the development of a cylindrical circulating flow. A smaller 1mm radius is provided on the downstream lower edge.

The device is intended to be used with the cavity openings facing upwards. However, since a cavity is only opened when there is already an airflow in the device and, it is believed that a circulating, shear driven flow is induced in the cavity before the powder has a chance to fall out of the cavity under gravity. In fact, it has been found that the performance of the device is largely independent of orientation.

In a modification of the third embodiment, the cavities have the shape of Design B (see Example 4). A cavity disc from the modified third embodiment, having cavities of this shape, is shown in Figure 16. The reference numerals correspond to those of Figure 6.

A fourth embodiment of the invention (not shown in the figures) is a single inhalation device containing one cavity with medicament powder in a simple cylindrical plastic case with an inlet and a mouthpiece. The cavity has the same geometry as one of the cavities of the third embodiment, and the flow passage above the cavity has the same dimensions. The flow passage communicates with the air inlet and the mouthpiece. In place of a lid member, the cavity is sealed with a foil strip which extends outside the housing of the inhaler and may be removed by pulling.

Throughout the description and claims of this specification, the word "comprise" and variations of the word, such as "comprising" and "comprises", is not intended to exclude other additives, components, integers or steps.

The discussion of documents, acts, materials, devices, articles and the like is included in this specification solely for the purpose of providing a context for the present invention. It is not suggested or represented that any or all of these matters formed part of the prior art base or were common general knowledge in the field relevant to the present invention as it existed before the priority date of each claim of this application.

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The claims defining the invention are as follows:

1. A dry powder inhaler device for dispensing an air stream carrying a dose of medicament powder, the device comprising a flow passage and a powder storage cavity having an opening, wherein the cavity opening is in a wall of the flow passage and the flow passage is arranged to direct a flow of air across the cavity opening, and wherein (i) the cavity opening has a quadrilateral shape, such as rectangular or trapezoidal, (ii) the length of the cavity opening in the flow direction is (i) between 50% and 150% of the cavity depth, and (ii) at least 80% of the maximum length of the cavity in the flow direction, (iii) the maximum height of the flow passage adjacent the cavity is between 0.5mm and 4mm, preferably between 0.5mm and 3mm, more preferably between 1mm and 2mm, and (iv) the lower front and/or rear edges of the cavity, with respect to the flow direction, have a radius of between 0.5 and 3 mm, preferably between 1.5 and 2.5 mm, more preferably between 1.75 and 2.25 mm..

2. A device as claimed in claim 1 wherein the cavity opening has fillet radii of 0.001mm to 0.5mm, preferably 0.01mm to 0.3mm.

3. A device as claimed in claim 1 or claim 2 wherein the opening has an aspect ratio in the range 1.5 to 4.0, preferably 1.8 to 3.5, more preferably 2.6 to 3.2.

4. A device as claimed in any preceding claim wherein the length of the cavity opening in the flow direction is between 105% and 140% of the cavity depth, preferably between 110% and 135%.

5. A device as claimed in any preceding claim wherein the maximum width of the flow passage in the region of the cavity is between 2mm and 6mm.

6. A device as claimed in any preceding claim wherein a lid member is associated with the cavity, movable between a first position in which the cavity is closed and a second position in which the cavity is open and the lid member provides part of the boundary of the flow passage.

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7. A device as claimed in any preceding claim wherein downstream of the said cavity, a second powder storage cavity opens into the flow passage.

8. A device as claimed in any preceding claim wherein a plurality of flow passages is arranged around the circumference of a circle, the flow passages being arranged such that the flow direction is radial with respect to the said circle, at least one said powder storage cavity being located in each flow passage.

9. A device for dispensing an air stream carrying a dose of medicament powder, the device comprising (a) a powder storage cavity having a single opening and (b) a lid member movable between a first position in which the cavity is closed and a second position in which the cavity is open, wherein when the lid member is in the second position it provides part of the boundary of a flow passage, the cavity opening being in a wall of the flow passage and the flow passage being arranged to direct a flow of air across the cavity opening, and wherein (i) the cavity opening has a quadrilateral shape, such as rectangular or trapezoidal, (ii) the length of the cavity opening in the flow direction is between 50% and 150% of the cavity depth, and (iii) the lower front and/or rear edges of the cavity, with respect to the flow direction, have a radius of between 0.5 and 3 mm, preferably between 1.5 and 2.5 mm, more preferably between 1.75 and 2.25 mm.

10. A device as claimed in claim 9 wherein, downstream of the said cavity, a second powder storage cavity opens into the flow passage and the second cavity is also closed when the lid member is in the first position and open when the lid member is in the second position.

11. A device as claimed in any preceding claim charged with medicament powder in the cavity or cavities.

12. A dry powder inhaler device for dispensing an air stream carrying a dose of medicament powder, the device comprising a flow passage and a powder storage cavity having an opening, wherein the cavity opening is in a wall of the flow passage and the flow passage is arranged to direct a flow of air across the cavity opening, and wherein the length of the cavity opening in the flow direction is (i) between 50% and

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150% of the cavity depth, and (ii) at least 80% of the maximum length of the cavity in the flow direction, wherein the flow passage adjacent the cavity has a cross sectional area in the range 1mm^2 to 20mm^2, preferably 3mm^2 to 10mm^2, and wherein the lower front and/or rear edges of the cavity, with respect to the flow direction, have a radius of between 0.5 and 3 mm, preferably between 1.5 and 2.5 mm, more preferably between 1.75 and 2.25 mm.

13. A method for dispensing an air stream carrying a dose of medicament powder comprising passing a flow of air across the opening of the powder-containing cavity of a device as claimed in any of the preceding claims.

14. A method for dispensing an air stream carrying a dose of medicament powder comprising passing a flow of air across the opening of a powder-containing cavity having, the length of the cavity opening in the flow direction being (i) between 50% and 150% of the cavity depth, and (ii) at least 80% of the maximum length of the cavity in the flow direction, wherein the velocity of the flow immediately adjacent the cavity opening is at least 15m/s and wherein the lower front and/or rear edges of the cavity, with respect to the flow direction, have a radius of between 0.5 and 3 mm, preferably between 1.5 and 2.5 mm, more preferably between 1.75 and 2.25 mm.

15. A method as claimed in any one of claims 13 or 14 wherein the velocity of the flow immediately adjacent the cavity opening is at least 20m/s, preferably at least 20m/s, more preferably at least 30m/s, more preferably at least 40m/s or as much as 50m/s.

16. A method as claimed in any one of claims 13 to 15 wherein residual powder in the cavity after the step of passing a flow of air across the opening amounts to between 0.1% and 10% by mass of the total mass of powder in the cavity prior to dispensing, preferably between 1% and 8%, more preferably between 1% and 5%.

17. A method as claimed in any one of claims 13 to 16 wherein the average surface shear stress over the lower half of the cavity during the step of passing a flow of air across the opening is at least 0.5Pa, preferably at least 1Pa, more preferably at least 1.5Pa.

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18. A method as claimed in any one of claims 13 to 17 wherein the average turbulent kinetic energy in the lower half of the cavity during the step of passing a flow of air across the opening is at least 3 m^2/s^2, preferably at least 4 m^2/s^2, more preferably at least 5 m^2/s^2.

19. A method as claimed in any one of claims 13 to 18 wherein the average vorticity in the lower half of the cavity during the step of passing a flow of air across the opening is at least 2,000 1/s preferably at least 4,000 1/s, more preferably at least 10,000 1/s.

20. A method as claimed in any one of claims 13 to 19 wherein the average flow velocity in the lower half of the cavity during the step of passing a flow of air across the opening is at least 1.5m/s, preferably at least 3m/s, more preferably at least 4m/s.

21. A device as claimed in claim 12 or a method as claimed in any one of claims 13 to 20 wherein the medicament powder contains an active ingredient selected from mometasone, ipratropium bromide, tiotropium and salts thereof, salemeterol, fluticasone propionate, beclomethasone dipropionate, reproterol, clenbuterol, rofleponide and salts, nedocromil, sodium cromoglycate, flunisolide, budesonide, formoterol fumarate dihydrate, terbutaline, terbutaline sulphate, salbutamol base and sulphate, fenoterol, 3-[2-(4-Hydroxy-2-oxo-3H-1,3-benzothiazol-7-yl)ethylamino]-N-[2-[2-(4-methylphenyl)ethoxy]ethyl]propane-sulphonamide, hydrochloride, indacaterol, aclidinium bromide, *N*-[2-(Diethylamino)ethyl]-*N*-(2-{[2-(4-hydroxy-2-oxo-2,3-dihydro-1,3-benzothiazol-7-yl)ethyl]amino}ethyl)-3-[2-(1-naphthyl)ethoxy]propanamide or a pharmaceutically acceptable salt thereof (e.g. dihydrobromide); *N*-Cyclohexyl-N^3-[2-(3-fluorophenyl)ethyl]-*N*-(2-{[2-(4-hydroxy-2-oxo-2,3-dihydro-1,3-benzothiazol-7-yl)ethyl]amino}ethyl)-β-alaninamide or a pharmaceutically acceptable salt thereof (e.g. di-D-mandelate); a [2-(4-Chloro-benzyloxy)-ethyl]-[2-((R)-cyclohexyl-hydroxy-phenyl-methyl)-oxazol-5-ylmethyl]-dimethyl-ammonium salt (e.g. hemi-naphthalene-1,5-disulfonate); a (*R*)-1-[2-(4-Fluoro-phenyl)-ethyl]-3-((*S*)-2-phenyl-2-piperidin-1-yl-propionyloxy)-1-azonia-bicyclo[2.2.2]octane salt (e.g. bromide or toluenesulfonate); or a combination of any two or more thereof.

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22. A replacement magazine for use in a device as described in any one of claims 1 to 12, the magazine comprising a cavity or cavities charged with medicament powder.

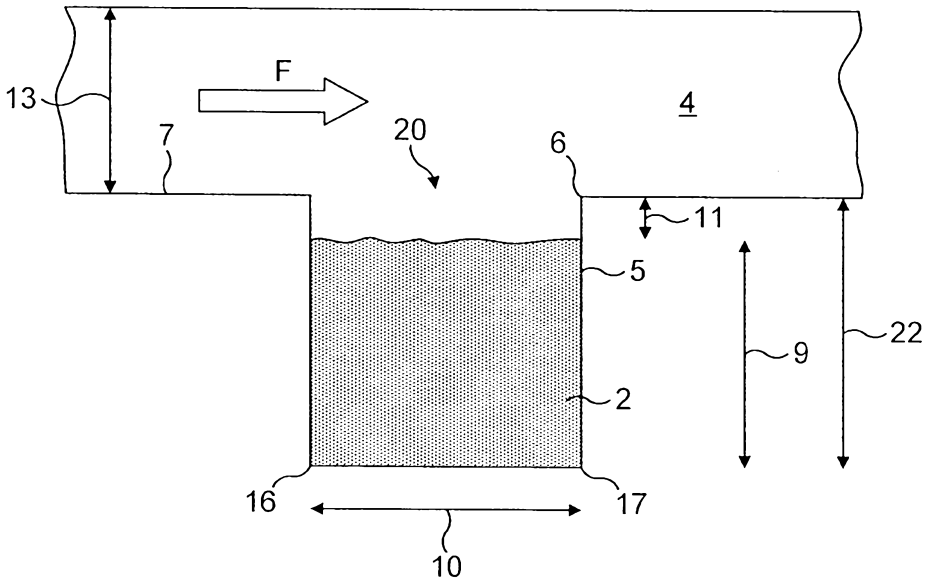

FIG. 1

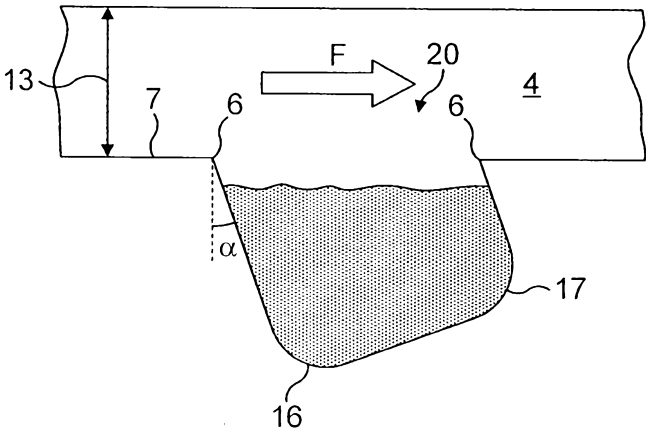

FIG. 2

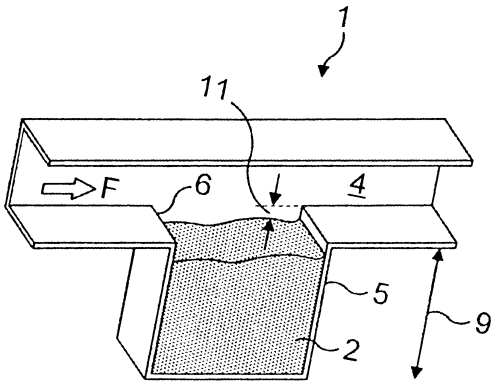

FIG. 3a

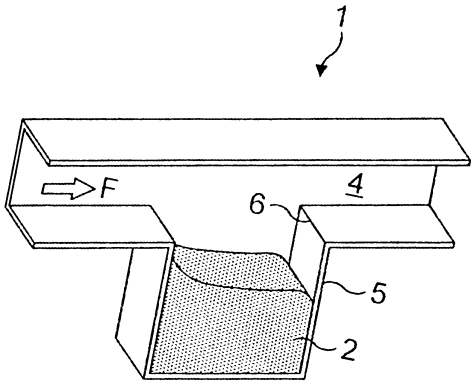

FIG. 3b

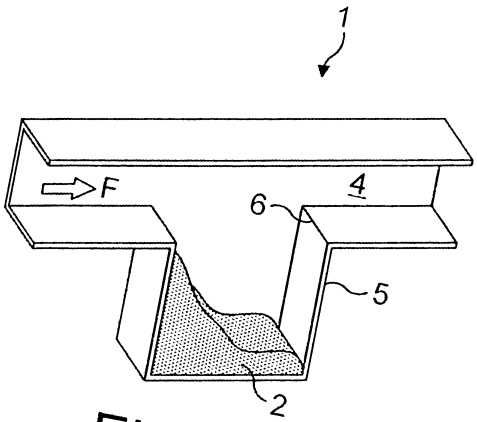

FIG. 3c

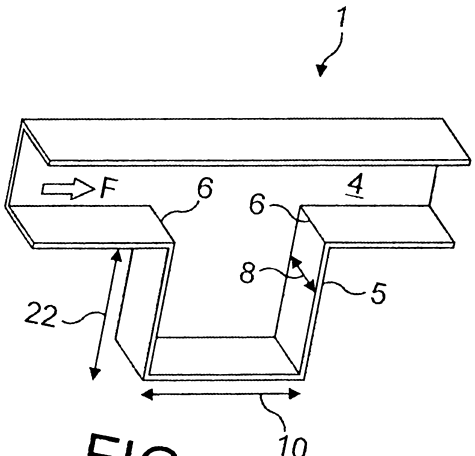

FIG. 3d

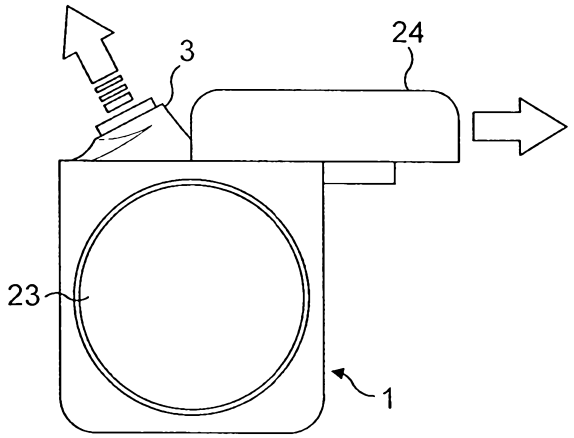

FIG. 4

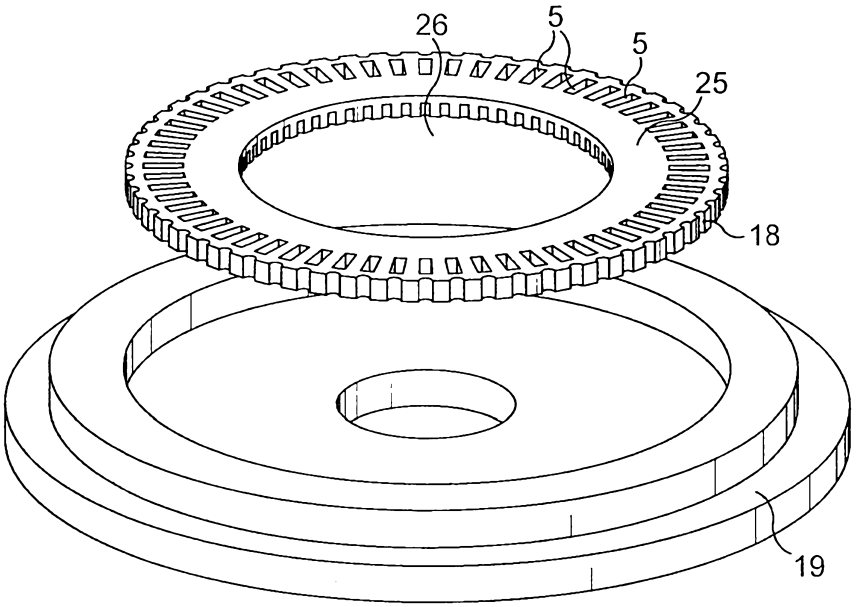

FIG. 5

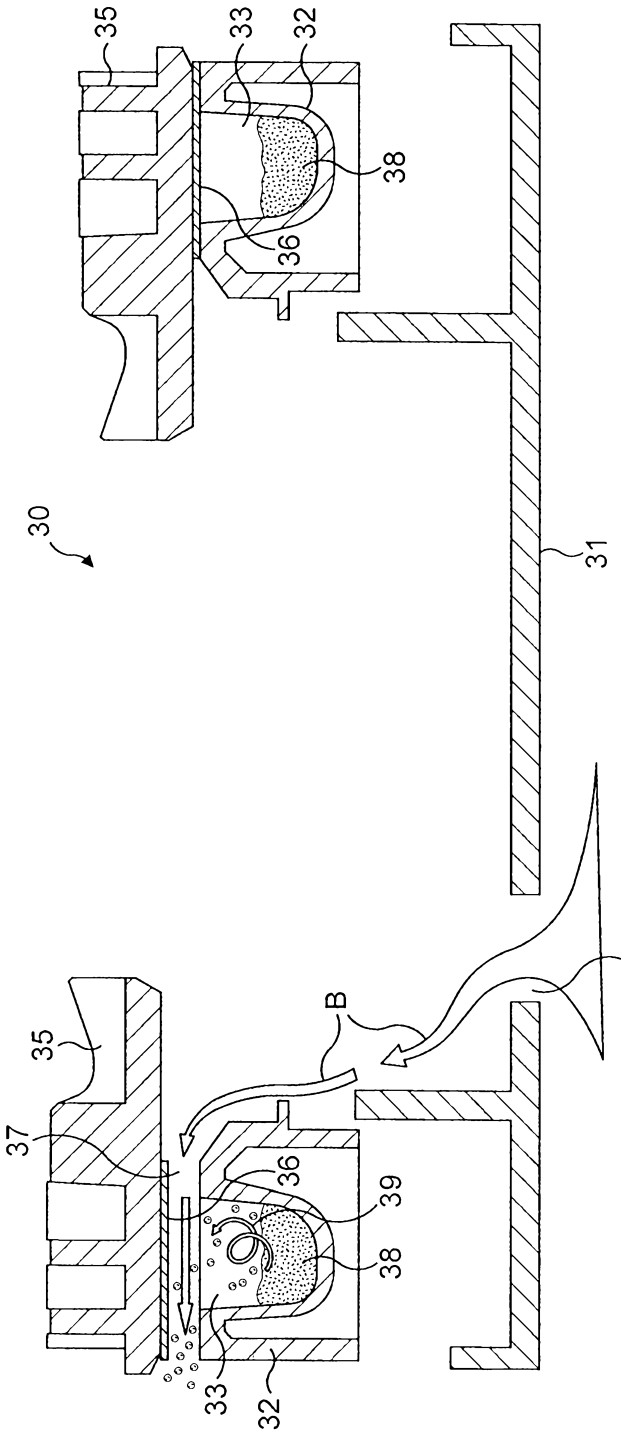

FIG. 6

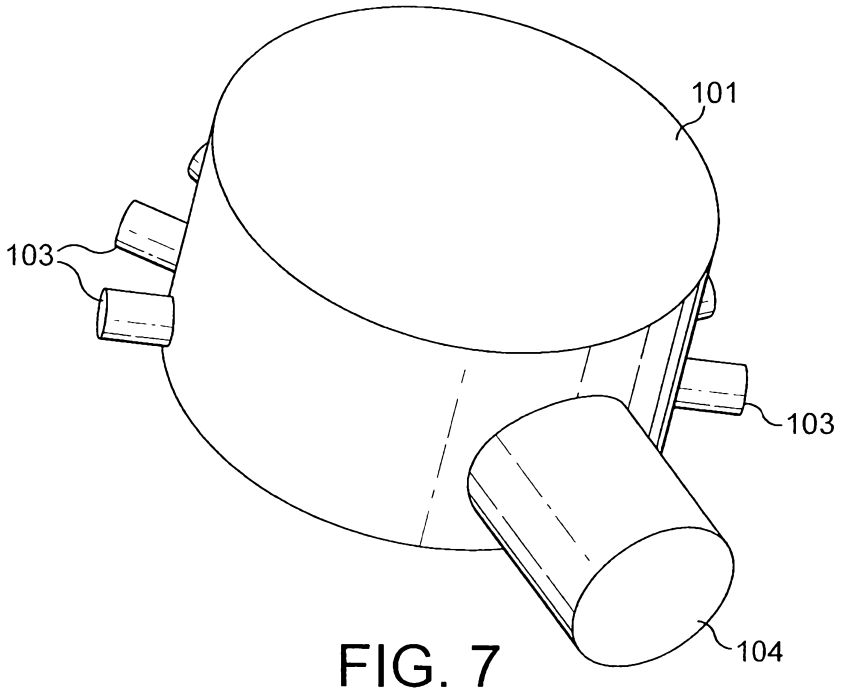

FIG. 7

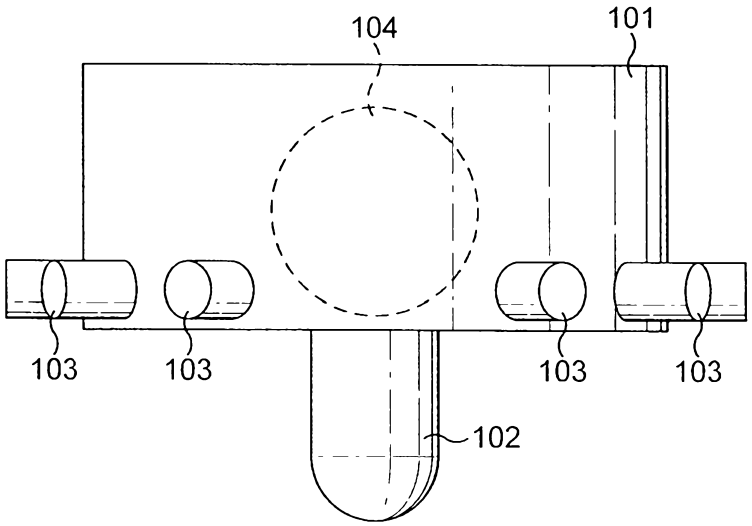

FIG. 8

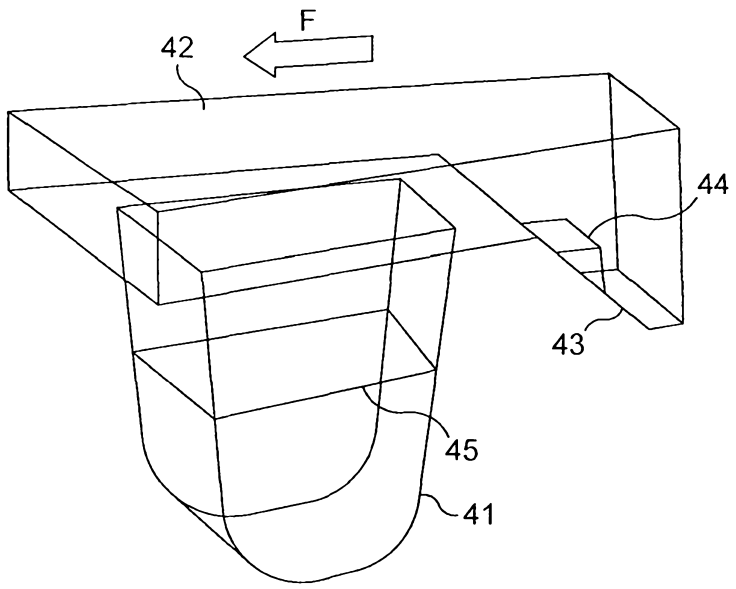
F
42
44
43
45
41

FIG. 9

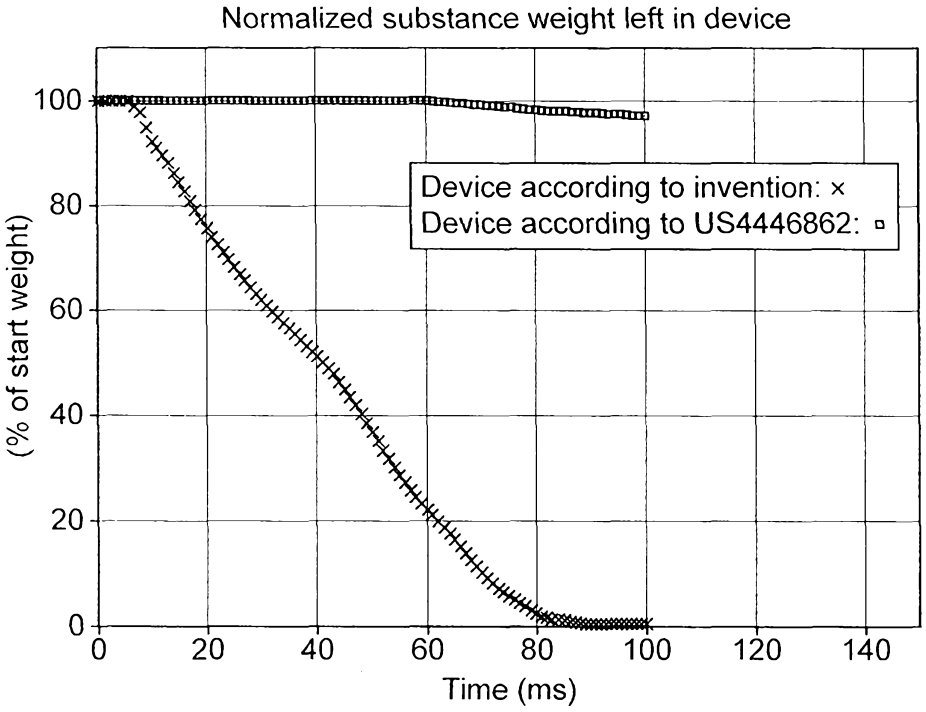
Normalized substance weight left in device
(% of start weight)
Time (ms)
Device according to invention: ×
Device according to US4446862: ▫
0
20
40
60
80
100
120
140

FIG. 10

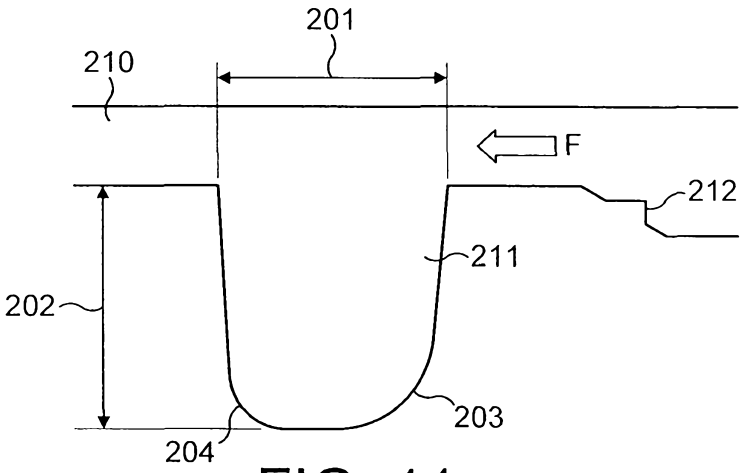

FIG. 11a

FIG. 11b

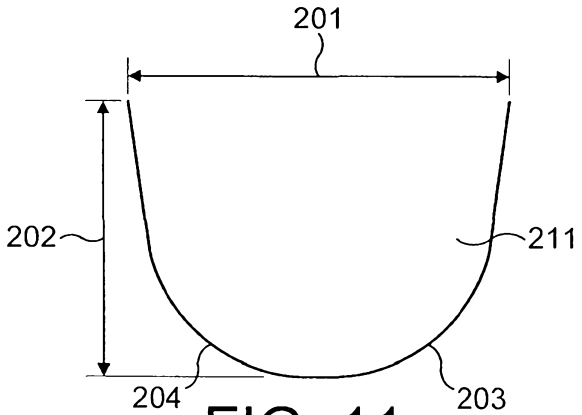

FIG. 11c

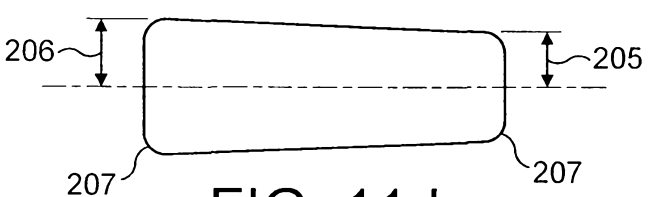

FIG. 11d

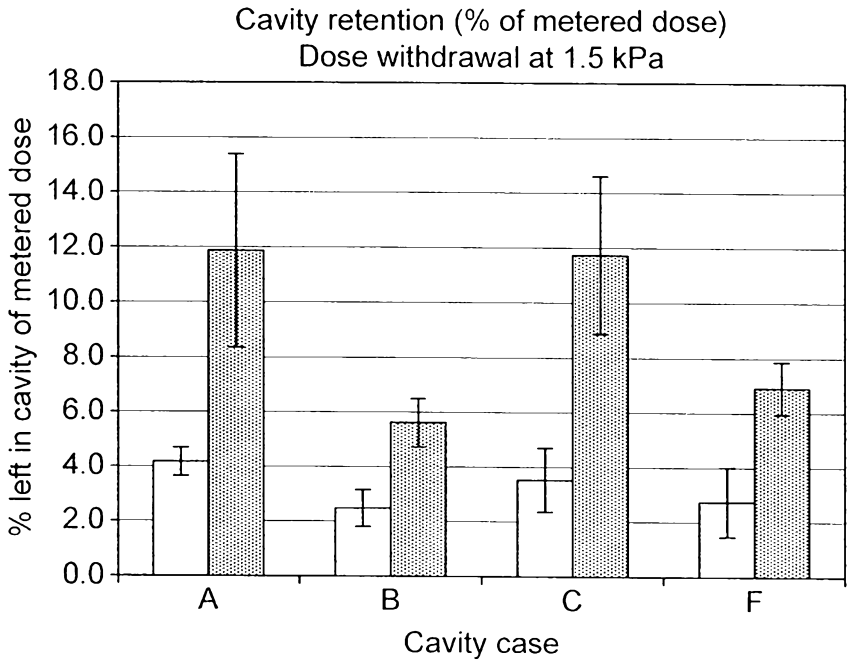
Cavity retention (% of metered dose)
Dose withdrawal at 1.5 kPa
% left in cavity of metered dose
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
A
B
C
F
Cavity case

FIG. 12

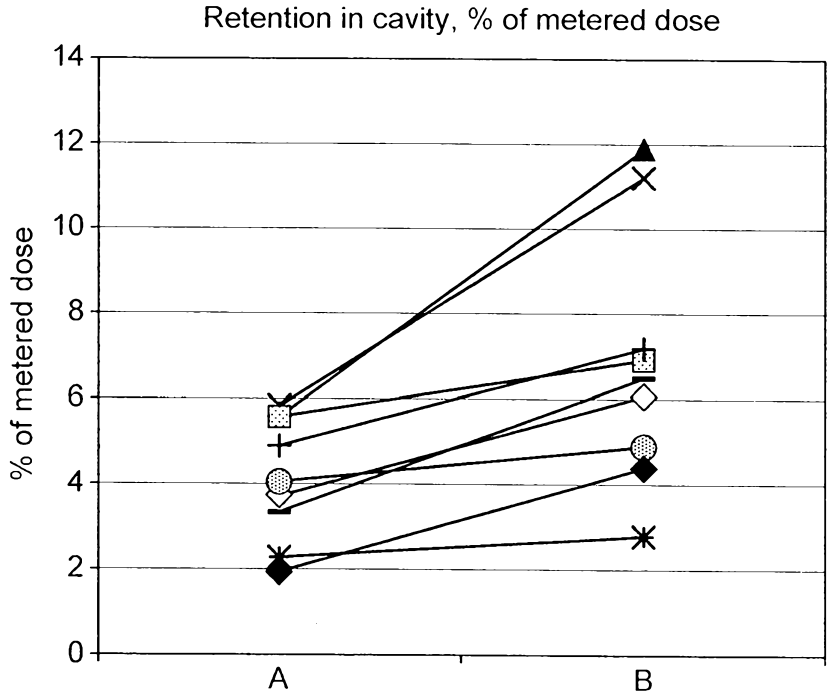
Retention in cavity, % of metered dose
% of metered dose
14
12
10
8
6
4
2
0
A
B

FIG. 13

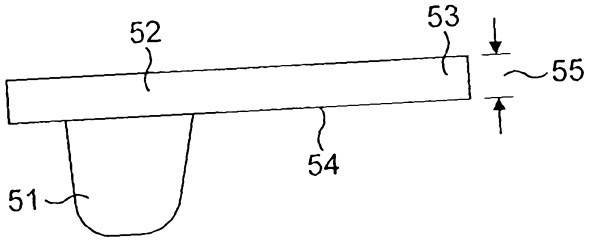

FIG. 14a

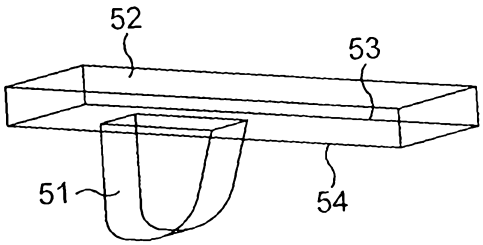

FIG. 14b

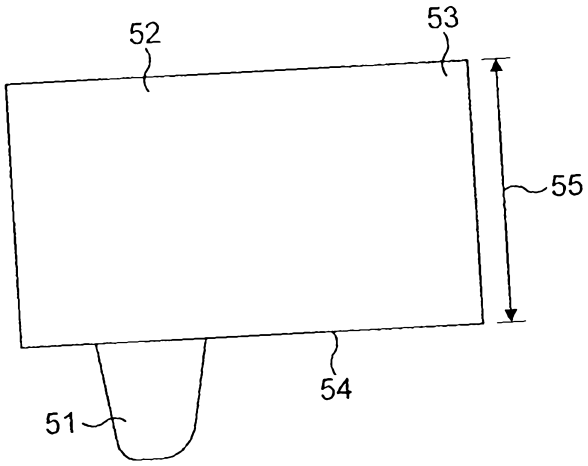

FIG. 15a

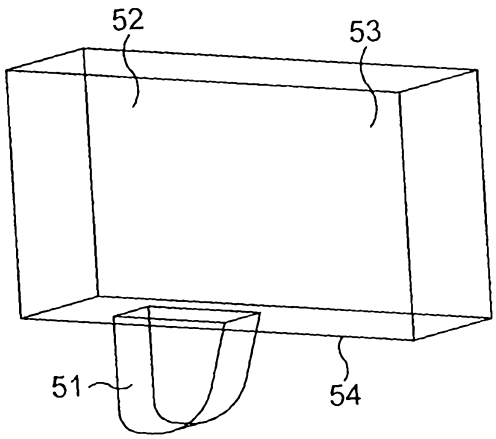

FIG. 15b

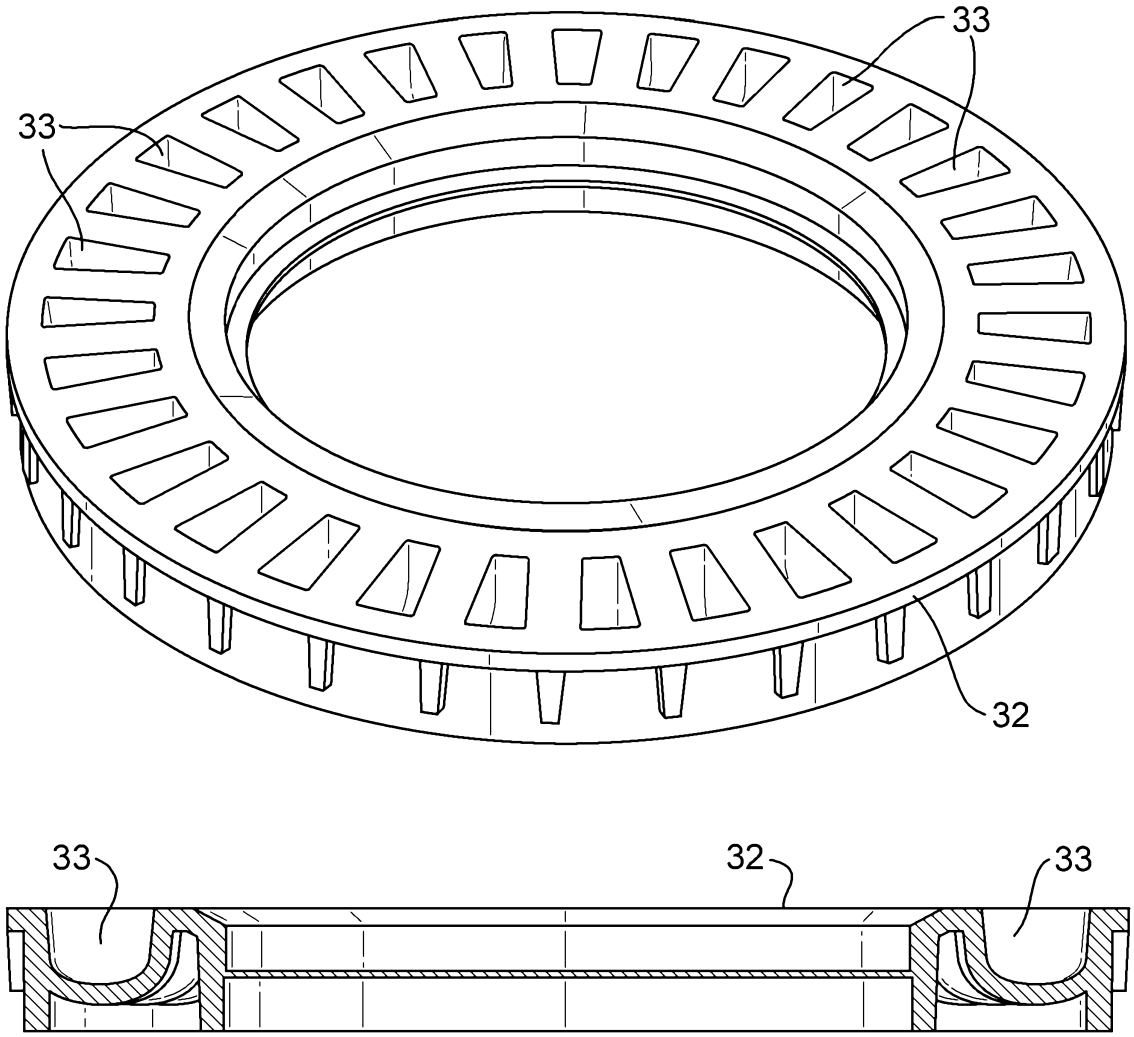

FIG. 16