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(54) **METHOD AND APPARATUS FOR DRYING PAPER CONTAINERS**

(57) The present invention relates to drying of a container by use of a generator for generating ultrasonic acoustic waves and an acoustic waveguide configured to guide acoustic waves generated by said generator into an interior of an associated container, said waveguide is configured to receive at least a part of a mouth section of said associated container in a position being distal from said generator.

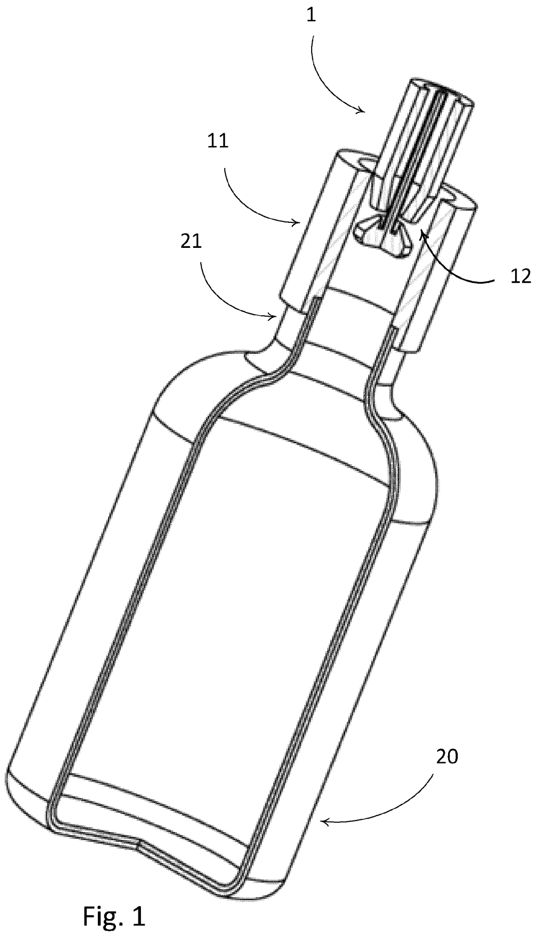

Fig. 1

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Description

FIELD OF THE INVENTION

[0001] The present invention relates to drying of a container by use of a generator for generating ultrasonic acoustic waves and an acoustic waveguide configured to guide acoustic waves generated by said generator into an interior of an associated container, said waveguide is configured to receive at least a part of a mouth section of said associated container in a position being distal from said generator.

BACKGROUND OF THE INVENTION

[0002] Containers, such as bottles, for food material have been produced from plastic for decades. Such plastic containers are prone to environmental pollution and are often produced from non-renewable materials. Although larger amount of plastic today is recycled for production of new containers, a container which is not made from plastic is in demand.

[0003] As an alternative to containers made of plastic, wet- and dry-moulded paper containers, such as a bottles, being produced from cellulose fibre, including paper pulp. To increase the shelf-life of the container when containing food materials, the containers may be provided with an interior barrier coating. Such containers are considered to be compostable and recyclable depending on how much fibres there are in the containers and what kind of barrier coatings are applied on the wall of the containers.

[0004] In general, the inner surface of containers is often processed with liquids. Typical examples are washing with water and liquid detergents, as well as deposition of protective and barrier coatings, including water-based coatings. Technological process in such cases includes drying of the inner surface, i.e. removal of vapours of volatile liquids, e.g. water vapor (moisture), alcohol, acetone etc.

[0005] In regard to wet-moulded paper bottles, drying is also an integral part of the moulding process since bottles formed from wet paper pulp, i.e. cellulosic fibres dispersed in water, and become rigid containers only after almost total removal of moisture.

[0006] Heating from the outside by means of contact, convective or even radiation heating by e.g. infrared or radio-frequency, particularly microwave, electromagnetic energy transfer is commonly used to cause thermally stimulated diffusion inside and thus accelerate the drying process and thereby the entire bottle production or surface processing.

[0007] However, heating is often insufficient for ensuring high drying rate required for mass production or processing of bottles. There are two interrelated phenomena inhibiting or at least slowing-down thermal drying of inner surface of bottles:

- A narrow entrance opening of a container enhances diffusion flow resistance at the bottle orifice and impedes ejection of a mixture of air and vapours from within the dried bottle into the environment. Hence, the partial vapour pressure in the head space increases and mass transfer of vapour (for instance, moisture transfer) from the inner surface slows down or even completely ceases.
- There is fundamentally a diffusion laminar boundary layer at the interface between liquid at the inner surface or simply the wetted (or wet) inner surface of a container. Gas molecules at the liquid-gas (or the solid-gas) interface move slow and the mass transfer is therefore decelerated.

[0008] The higher the partial vapour pressure in the head space becomes, the thicker the laminar boundary layer at the inner surface, and vice versa. This means, first, that thermal drying of containers is inefficient, especially if heat is transferred from outside. Moreover, neither injection of hot air into the container nor just suction of air mixed with vaporized liquid out of the container will substantially enhance the drying process.

[0009] Thus, while such wet-moulded paper container can be produced to contain and store food material, the production process today has the drawback that drying of the containers is an energy-intensive and ineffective process.

[0010] Hence, an improved drying of wet-moulded paper containers would be advantageous, and in particular a less energy-intensive and more efficient and/or reliable drying would be advantageous.

OBJECT OF THE INVENTION

[0011] It is an object of the present invention to provide drying of wet-moulded paper containers that solves one or more of the above mentioned problems. It is a further object of the invention to provide a more efficient drying of wet-moulded paper containers.

SUMMARY OF THE INVENTION

[0012] Thus, the above described object and several other objects are intended to be obtained in a first aspect of the invention by providing an apparatus for drying a wall of a container, comprising

- a generator for generating ultrasonic acoustic waves having:
    - a nozzle comprising an interior flow channel having an inlet and a narrowing section downstream of the inlet and proceeding towards an outlet;
    - a resonator comprising a cavity having an open end facing towards said outlet and arranged in a distance from said outlet;
    - a stem having a diameter being less than a diameter of said outlet, said stem arranged co-axially with a longitudinal axis of said narrowing section and extending from a bottom of said cavity through said outlet and at least to a position inside said flow channel being upstream of said narrowing section;
- an acoustic waveguide configured to guide acoustic waves generated by said generator into an interior of an associated container, said waveguide comprising a tubular element being
    - dimensioned to accommodate at least a section of said nozzle comprising said narrowing section and to accommodate said resonator with a clearance providing a flow path between an inner wall of said tubular element and said section of said nozzle and said resonator, and

  configured to receive at least a part of a mouth section of said associated container in a position being distal from said resonator.

[0013] Terms used herein are used in manner being ordinary to a skilled person. Some of the used terms are elucidated here below:
"Generator" is used interchangeably with *"generator for generating ultrasonic acoustic waves".*
[0014] *Downstream* refers to a direction in which a fluid flows. *Upstream* refers to a direction being opposite to a direction in which a fluid flows. A flow direction may be indicated by a upstream inlet and a downstream outlet.
[0015] *Moisture* preferably refers to water in the form of vapour and/or liquid, such as droplets and/or aerosols. Moisture can e.g. be present in a solid material, such as in the wall of a container or in air in a gas phase, such as in air contained in a container.
[0016] *Diffusion* preferably refers to non-solid substances, such as moisture, escaping from a surface of an inner the wall of a container into a flow boundary layer formed on the inner wall. Without being bound by theory, the transport of the non-solid substances during enhancement of the diffusion may be explained as follows. During diffusion, a deficit of non-solid substances is created between the interior volume of the container and inside the wall of the container. This deficient is sustained by a flow of gas (air) carrying the non-solid substances diffused into the gas (air) and being ejected from the container through a mouth section. The generator creates what may be referred to a Venturi effect at the generator interior to the waveguide with a lower pressure than the pressure exterior to the container resulting in an inflow of ambient gas (air) into the container. The pressure generated by the Venturi effect is also lower than the pressure inside the container, whereby gas (air) is sucked out from the interior of the container and ejected to the exterior of the container. The inflow of air dilutes the non-solid content in the gas interior of the container whereby the gas inside the container has a low partial pressure of the non-solid substances. As at least an approximation, non-solid substance(s) contained in the wall of the container may be considered as either liquid or gas or a combination thereof, such an essential gas having an equilibrium between gas and liquid. Thus, a concentration gradient exists between the non-solid substance(s) inside the container and at the wall of the container, which gradient gives rise to a concentration boundary layer. The transport of non-solids substance(s) from the wall to the gas inside the container is substantially driven by the magnitude of the concentration gradient across the concentration boundary layer and by exposing the presumably laminar flow boundary layer to ultrasonic acoustic waves, the flow boundary layer typically changes from a laminar to a turbulent boundary layer, which has the effect of steepening the concentration gradient across the concentration boundary layer which results in an increased diffusion of non-solids from the wall of the container.
[0017] *Enhancing diffusion of a non-solid substance(s) from a wall* refer to an enhanced diffusion as detailed above under *"Diffusion". Enhanced* may be evaluated relatively to natural diffusion being a situation with no ultrasonic acoustic waves acting on the flow boundary layer.
[0018] *Acoustic turbulent boundary layer* preferably refers to a flow boundary layer which has been made turbulent and/or where the intensity of turbulence of the boundary layer has been increased due to interaction with ultrasonic acoustic waves.

[0019] *Wet- and dry-moulded paper container* preferably refers to a container, such as a bottle, being produced from cellulose fibre, including paper pulp. In regards to the present invention, drying of a dry-moulded container refers in particular to drying of a liquid coating applied to an inner surface of such a dry-molded container.

[0020] *Non-solid substance(s)* preferably refers to volatile liquid(s), such as water, one or more essential oils, typically being in gas liquid equilibrium at normal atmospheric conditions, vapours of aromatic hydrocarbons (fuels), alcohol, acetone and other volatile solvents.

[0021] *Drying* preferably refers to a combination comprising enhancing diffusion of non-solid substance(s) and extraction from the interior of the container of fluid, typically a gas, containing the non-solid substance(s). In preferred embodiments non-solid substance(s) is water.

[0022] *Bottle* preferably refers to a narrow-necked packaging container. The container may have various shapes and sizes and is preferably used to store and/or transport liquids.

[0023] In a second aspect, the invention relates to a method of drying a container, the method utilizes an apparatus according to the first aspect of the invention. The method comprises

- providing a wet-moulded paper container or a dry-moulded container having an interior liquid container, where said container has a mouth section,
- receiving at least a section of said mouth section of said container in said tubular element, and
- feeding pressurized gas into said inlet.

BRIEF DESCRIPTION OF THE FIGURES

[0024] The present invention and in particular preferred embodiments thereof will now be described in more detail with regard to the accompanying figures. The figures show ways of implementing the present invention and are not to be construed as being limiting to other possible embodiments falling within the scope of the attached claim set.

Fig. 1 schematically illustrates in a 3-dimensional view a bottle and an apparatus for drying according to a preferred embodiment. The apparatus and bottle are both illustrated with a quarter section cut away to show interior structures;

Fig. 2 schematically illustrates the embodiment of Fig. 1 in a cross sectional view including an enlarged view of a generator according to a preferred embodiment;

Fig. 3 schematically illustrates a method of drying of a container according to a preferred embodiment; the container illustrated is the container illustrated in Fig. 1 and 2 and is, as in Fig. 2, illustrated in a cross sectional view.

Fig. 4 schematically illustrates a preferred embodiment of generator in a cross sectional view. Fig.4 details a preferred way to evaluate a depth *h* of a cavity and a length *l,* i.e. the separation between the nozzle and the resonator. Δ_0 is a shock cell length. Upper part of Fig. 4 shows a flow situation in which fluid leaving the nozzle is ejected to the exterior, and lower part of Fig. 4 shows a flow situation in which fluid leaving the nozzle flows in opposite direction and into e.g. a container.

Fig. 5 shows a generator according to a preferred embodiment. The generator is used to produce the results presented in Fig. 6

Fig. 6 is a graph illustrating relative moisture loss versus time, being results obtained in an "Experiment 1".

Figs. 7-9 are graphs illustrated experimental results obtained in an "Experiment 2".

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0025] Reference is made in particular to Fig. 1 and 2. In Fig. 1 a 3-dimension view of a bottle and an apparatus for drying a container is shown. The container is in the illustrated embodiment a bottle, but the invention is not limited to drying of bottles as other forms of containers may be dried by an apparatus according to preferred embodiment. Drying the bottle is based on enhancing diffusion of non-solid substance(s) from a wall of the bottle. In the illustrated embodiment, the bottle is a wet-moulded paper bottle and non-solid substance(s) is water contained within the wall of the bottle.

[0026] Although the following description is made with reference to water as non-solid substance(s) and the container being a bottle, this description is to be construed as non-limiting to the scope of the claims.

[0027] The illustrated apparatus for drying a container 20 comprises a generator 1 for generating ultrasonic acoustic waves 16. The generator is configured to direct, during use, ultrasonic acoustic waves into a void of the bottle. With reference to the upper right part of Fig. 2, the generator 1 has a nozzle 2 forming an interior flow channel 3 with an inlet 4 and a narrowing section 5 downstream of the inlet 4. The narrowing section 5 proceeds toward an outlet 6. As schematically illustrated in Fig. 3, the inlet 4 is fluidically connected to a pressurized air source 17 in a manner allowing the pressurized air to flow into the interior flow channel 3 and leaving the interior flow channel 3 only through the outlet 6.

[0028] Accordingly, the pressurized air is accelerated by the narrowing section 5 and leaves the outlet 6 at supersonic speed.

[0029] A resonator 7 is arranged downstream of the outlet 6. Downstream refers to a direction relatively to the flow direction in the interior flow channel 3. A purpose of the resonator 7 is to allow for resonance of the ultrasonic acoustic wave formed.

[0030] The resonator has a cavity 8 with an open end 9 facing towards the outlet 6. In the illustrated embodiment, the cavity 8 is in the form of a hollow cylinder. The open end 9 is arranged in a distance from the outlet 6. The distance may be selected as disclosed below.

[0031] The generator further has a stem 10 having a diameter being less than a diameter of the outlet 6. As illustrated, the stem 10 is arranged co-axially with a longitudinal axis of the narrowing section 2 and the stem 10 extends from a bottom of the cavity 8 through the outlet 6 and to a position inside flow channel 3, preferably being a position upstream of the narrowing section 5.

[0032] While the stem 10 is a mechanical feature used to position the resonator in a fixed position relatively to the outlet 6, the stem 10 by its extending through the outlet 6 will also assist in accelerating the air due to the stem reducing the area of the outlet 6 relatively to a situation where the stem 6 does not extends through the outlet 6.

[0033] The stem 6 is maintained in a fixed position relatively to the nozzle 2 by suitable fixations (not illustrated). In some embodiments, the distance between the outlet 6 and the open end of the cavity 9 is made adjustable by allowing for longitudinal movement of the stem 6 while still allowing for fixation of the stem 6.

[0034] As a purpose of preferred embodiment is to feed ultrasonic acoustic wave into the interior of the bottle, the apparatus comprises an acoustic waveguide 11. The waveguide 11 is configured to guide acoustic waves generated by the generator into the interior of the bottle. In the illustrated embodiment, this configuration is provided by the waveguide 11 has a tubular element, typically being cylindrical, which is dimensioned to accommodate at least a section of the nozzle 2. The section of the nozzle accommodated includes the narrowing section 5 and the resonator 7. Including the narrowing section 5 here refers to the part of the nozzle inside which the narrowing section 5 extends. A clearance 12 (see Fig. 1) is provided between an inner wall of the tubular element and the accommodated section of the nozzle 2 and the resonator 7. This clearance 12 providing a flow path to exchange air between the interior and exterior of the bottle.

[0035] From a fluid dynamic perspective, the reversed flow 25 shown in Fig. 3 may be characterised by a Reynolds number based on the magnitude of velocity *v* at the orifice, labelled δ in Fig. 5, of the reversed flow 25 and the magnitude of the orifice:

$$Re = \frac{v\delta}{\nu}$$

which will be detailed further below. ν is the kinematic viscosity.

[0036] The waveguide 11 is also configured to receive at least a part of a mouth section 21 of bottle in a position being distal from said resonator 7. In the illustrated embodiment, the tubular element has an interior recess 22 which mates with the exterior geometry of the mouth section 21 of the bottle.

[0037] It is generally preferred that the interior surface of the waveguide is provided, e.g. polished to level, so that unevenness in the surface substantially does not cause disturbances of the ultrasonic acoustic waves when they propagate away from the generator 1 and into the interior of the bottle. Further, it is generally preferred that the interior wall of the mouth section 21 of the bottle and the interior wall of the waveguide, at least below the resonator 7 form a substantial coherent surface with only minor discontinuities at the interface between the interior surface of the bottle and interior surface of the waveguide 11, so as to avoid or minimize disturbances of the ultrasonic acoustic waves propagating into the bottle.

[0038] In preferred embodiments, the narrowing section 5, the cavity 8 and at least a section of the stem 10 extending through the outlet 6 are rotational symmetric.

[0039] In preferred embodiments, the generator is a so-called stem-jet Hartmann type generator.

[0040] Reference is made in particular to Fig. 3 and Fig. 4. In Fig. 3 a preferred flow regime is schematically depicted with the interior air flow labelled 19. The reversed flow 25 of the flow out of the nozzle 2 is shown as a flow turning backward, such as essentially 180 degrees, and flows out to the exterior through the upper end of the waveguide 11. This turning of the flow from the nozzle creates a Venturi effect with a pressure at an upper section of the waveguide 11 being relatively lower than the pressure in the interior of the bottle. This Venturi effect creates a suction which sucks out air from the interior of the bottle and giving it momentum so as to be ejected to the exterior. And, as the wall of the bottle is essentially impermeable to air, air will also be sucked into the interior of the bottle from the exterior due to the Venturi effect. In Fig. 3 the air inflow 24 as well as the exhaust air flow 23 (outflow) are depicted by arrows. Upper part of Fig. 4 depicts the flow in the vicinity of the resonator 7 as also shown in Fig. 3. Due to the rotational symmetry of the generator and wave guide the flow in the vicinity of the generator is rotationally symmetric.

[0041] The lower part of Fig. 4 illustrates a less favourable flow regime in which the flow out of the nozzle 2 is not turned backward, but instead flows in direction toward the interior of the bottle. The two different flow regimes of Fig. 4 is selectable *inter alia* by design of the generator 2. The selection of flow regime may be based on a relation like the following equation:

$$1.3\Delta_0 \leq l + h < 2.0\Delta_0$$

where *l*, *h* are evaluated as depicted in Fig. 4 and Δ_0 is a shock cell length. Thus, if *l*+*h* falls within the limits of the equations, the flow regime depicted in the upper part of Fig. 4 can be obtained. If not, a flow regime depicted in the lower part of Fig. 4 is obtained.

[0042] Accordingly, in preferred embodiments, the cavity 8 has a depth *h* and the resonator 7 is arranged in a distance *l* evaluated between the outlet 6 and the open end 9 so that the sum of the depth *h* and distance *l* is larger than 1.3 times a shock cell length Δ_0 and smaller than 2.0 times the shock cell length Δ_0.

[0043] The shock cell length Δ_0 may be determined by empiricism between pressure of the air and the area of the outlet 6. Thus, in preferred embodiments, the pressure of the air to be used is selected (by a user) and the area of the outlet 6 are defined (by a user) whereby Δ_0 can be determined. Once Δ_0 is determined, the depth *h* and length *l* can be selected (by a user) in accordance with the above formula.

[0044] Preferred embodiments aim at providing a sound pressure level *SPL* of the ultrasonic acoustic waves above a predefined level. While *SPL* can be measured, it may also be estimated and used in a design process for preferred embodiments of the invention.

[0045] According to experiments, enhancement of diffusion caused by the ultrasonic acoustic waves is highly effective when the SPL is above what may be referred to as a critical sound pressure level:

$$SPL_{cr} \geq 136 + 10\ log_{10}(f)\ \text{(in dB)},$$

where *f* is the frequency expressed in kHz. It is noted, that this formula is based on empiricism where the constant "136" has the unit dB and the function 10 $log_{10}(f)$ is assigned to give a number in dB although the frequency *f* has the unit kHz.

[0046] Typical preferred numbers for the frequency and the critical sound pressure level is $SPL_{cr} \geq 151$ dB and a frequency above audible region, such $25\ kHz \leq f \leq 35\ kHz$.

[0047] In the below section detailing experiments, details as to a particular preferred embodiment are disclosed. These details can advantageous form basis for designing variations. When such variations are considered, the following guiding can be used e.g. in combination with computational fluid dynamics (CFD):

Table 1 - typical dimensions and process parameters

Pressure, *P*, of gas flowing into the nozzle 2	*1.9 bar < P < 3 bar*
Sound pressure level (preferably, substantially anywhere inside the bottle), *SPL*	*SPL > 151 dB*
Frequency, *f*	*25 kHz < f < 35 kHz*
Shock cell length, Δ_0	Δ_0 = 2.85 mm
Dimensions *l*+*h*	$1.3\Delta_0 \leq l + h < 2.0\Delta_0$
Diameter of outlet 6 (nozzle)	7 mm
Diameter of stem (10)	6 mm
Outer diameter of cavity 8	9.5 mm
Ratio of the resonator and stem diameters	1.58-1.6
Size of orifice δ	$\delta = \frac{\nu \cdot Re}{v}$ *where Re* = 2.900 - 30.000
v (speed of reversed flow 25 at δ see Fig. 5)	15-35 m/s

[0048] During drying, the flow regime illustrated in the upper part of Fig. 4 is preferred since the flow regime comprises (as also detailed above), a reversal of the flow out of the nozzle creating a Venturi effect which sucks in air 24, and sucks out air from the interior of the bottle. To provide such a flow regime in preferred embodiment, the exterior dimensions of the section of the nozzle 2 accommodated in the tubular element and the resonator 7, and interior dimension of the acoustic waveguide 11 are mutually configured to provide the clearance 12 with cross sectional area allowing for generating the Venturi effect to suck in of exterior flow, and extraction of gas from the interior of the container by sucking out gas from the bottle.

[0049] Accordingly, when a dimension for the clearance δ, distance *l* and depth *h,* and the diameters of the stem, the nozzle and the resonator have been selected, the pressure of gas into the nozzle may be in need of tuning so as to provide the following effects:

- Reversal of the flow out of the nozzle
- Sucking in of ambient air
- Sucking out of air from the bottle
- A sound pressure level larger than 151 dB (substantially anywhere inside the container).

[0050] As a rule of thumb, if the Reynolds number

$$Re = \frac{v\delta}{\nu}$$

is too high, the momentum of the reversed flow will be too high to allow for sucking air in and out. On the other hand, if the Reynolds number is too low, the Venturi effect may be too small to create the sucking in and out. Without being bound by theory, the inventor suggests aiming at a Reynolds number larger than 2.900 and smaller than 30.000.

[0051] As an approximation, the velocity may be calculated as evaluated based on

$$v = \frac{Q}{area}$$

[0052] Where *Q* is the total volume flow through the nozzle and *area* is a minimum cross sectional flow area between the generator and the wave guide. This may be evaluated based on δ in Fig. 5. Accordingly, the magnitude of the clearance 12, for Reynolds number calculations being the magnitude of δ, can be determined based on the Reynolds number necessary to provide an efficient Venturi pump functionality.

[0053] While the apparatus disclosed above is capable of drying a wall of a container, it may be advantageous to use one or more heat sources configured for providing an elevated temperature in a heating region downstream of the tubular element and into which said ultrasonic acoustic waves propagates. By providing heat in the heating region, the temperature of the interior of the bottle as well as the wall(s) of the bottle is raised. By an increase in temperature, the temperature of the air inside the bottle is increased which result in that a higher amount of water can be contained in the air. This has a positive effect on the diffusion of water from the wall into the interior of the bottle resulting in a decrease in drying time. Accordingly, preferred embodiments comprise such one or more heat sources.

[0054] Preferred embodiments of the heat source(s) is (are) configured to transfer heat by contact heating, convection heating and/or radiation heating. The transfer of heat is typically from the exterior of the bottle, through the wall of the bottle and into the interior of the bottle. In contact heating, a mechanical contact is provided between at least a section of the outer wall of the bottle and the heat source. In convection heating a heated medium, such as air, flow past at least a section of the outer wall of the bottle.

[0055] In preferred embodiments, the one or more heat sources is selected from electrical heaters, such as ohmic heaters, radio-frequency electromagnetic waves (particularly microwaves) heaters, Peltier elements, infrared radiation sources.

[0056] An apparatus according to any one of the preceding claims, wherein said apparatus further comprising a pressurised gas source 17, such as pressurized atmospheric air, configured to provide a flow of pressurized gas with a pressure being larger than 1.6 bar and smaller than 4.5. The gas source 17 may advantageously be configured to provide the flow of pressurized gas at selectable pressure levels so as to allow for changes in the pressure to e.g. set the pressure at a level where the generator 1 generates ultrasonic acoustic waves at a desired sound pressure level.

[0057] In preferred embodiments, the amount of pressurized gas is provided in the range of 15-25 Nm^3/hour typically having pressure between 1.9-3.0 bar(g). It is noted, that the establishment of a supersonic flow of is dependent of a pressure and the magnitude of the outlet 6 of the nozzle 2, and for air the pressure is to be larger than 1.9 bar(g).

[0058] In preferred embodiments, the pressurised gas source 17 comprising a compressor.

[0059] In preferred embodiments, the air leaving the generator 1 will not enter into the interior of the container. Thus, the risk of introducing contaminants into the interior of the container originating from the source of pressurized gas is limited. Accordingly, the gas from the source of pressurized gas may not be in need of cleaning or disinfection, although it could be advantageous to make sure that no unwanted matter ends up in the generator 1 while being carried by the pressurized gas.

[0060] On the other hand, since gas, e.g. air, is sucked into the interior of the container from the exterior, it may be advantageous to make sure that the exterior gas, e.g. air, does not contain contaminants such as germs or other potential hazardous elements. Here hazardous refers to negative effects on the human or animal body.

[0061] Atmospheric air is typically preferred for drying purposes as air is readily available, typically sufficiently clean to be used for drying. However, other types of gas such as helium, argon, nitrogen, or super-heated steam.

[0062] Many containers, and in particular bottles, are equipped with an external thread at a mouth section to receive a screw-on cap to close the container. In preferred embodiment, the tubular element 12 is configured to receive such a mouth section 21 by having an internal thread configured to co-operate with the thread of the container so that the mouth section is screwed into the tubular element 12.

[0063] In many preferred embodiments, the narrowing section 5, the cavity 8 and at least a section of the stem 10 extending through the outlet 6 are rotational symmetric. This typically means that the elements are rotational symmetric around an axis passing through a longitudinal center line of the stem 10.

[0064] Preferred embodiments of the invention relates to a method of drying a container such as a bottle. The method utilizes a preferred embodiment of an apparatus for drying as disclosed herein.

[0065] The method involves a step of providing a wet-moulded paper container, such as a bottle having a mouth section. This container is arranged so that at least a part of its mouth section 21 is received in the tubular element 12. Following this arrangement of the container, pressurized air is fed into the inlet 4 of the generator.

[0066] In preferred embodiments, the pressure and volume flow of the pressurized gas are selected to provide ultrasonic acoustic waves having a first harmonic frequency between 30-32 kHz and a sound pressure level, measured at a bottom of the container, larger than 157 dB. Here, bottom of the container typically refers to a position being located farthest away from the generator determined in a direction aligned with a longitudinal direction of the generator.

[0067] Preferably, the pressure of the pressurized gas preferably has a pressure between 1.9 bar(g) and 3.0 bar(g). However, the gas may be pressurized to level exceeding 3.0 bar(g). A pressure level below 1.9 bar(g) may result in sub-sonic flow whereas a pressure level above 1.9 insures in supersonic flow which is needed to provide ultrasonic acoustic waves.

[0068] The volume flow of the pressurized gas is preferably selected between 15 and 25 Nm^3/hour (normal cubic meters / hour). This interval has been found to provide a workable generation of ultrasonic acoustic waves in particular with a generator having dimensions provided in Fig. 5. As detailed above, the pressure of the pressurized gas is typically between 1.9 and 3 bar(g). However, if the generator shown in Fig. 5 is geometrically scaled up or down, the volume flow may be scaled accordingly.

[0069] As the drying process is at least to some larger extends governed by the ultrasonic acoustic wave and the Venturi effect, low temperature gas can be used. In preferred embodiments, the temperature of the gas is selected larger than 15°C, such as larger than 20°C, and smaller than 50°C, such as smaller than 40°C.

[0070] As the drying involves the Venturi effect which sucks exterior gas into the container and a need exists for avoiding or limiting entrance of contaminants into the container due to the Venturi effect, the method may be carried out in an manner where the gas(ses) inlet to the inlet 4 has the same, such as substantial the same, level or even a lower level of contaminants, such as germs or other potential hazardous elements, than the level of contaminants in the atmosphere exterior to the container which is sucked into the container. In preferred embodiments, the gas(ses) inlet to the inlet 4 is the gas of the atmosphere exterior to the container.

[0071] The gas supplied to the generator must, preferably, not have higher content of contaminants than that in the exterior air. Buy other words, working gas should preferably have the same cleanness and quality as those of the gas in the surroundings.

[0072] In particular preferred embodiments, the gas is atmospheric air preferably having a relative humidity less than 50% RH at 23°C. Use of atmospheric air is advantageous since it is readily available in larger quantities.

[0073] In preferred embodiments, the atmospheric air prior to pressurization is untreated atmospheric air, and the pressurized air is only treated to remove detritus and/or oil contamination originating from the pressurization prior to being fed into said inlet 4. Untreated, preferably refers to that the atmospheric air is used as it is without taking cleaning and/or sterilisation measures.

[0074] As detailed herein, a container is preferably a wet-moulded paper bottle or dry-molded paper bottle having a interior liquid coating. The wet-moulded paper bottle or dry-molded paper bottle being produced from cellulose fibre, including paper, pulp.

EXPERIMENTAL RESULTS PERTAINING TO DRYING OF BOTTLES

Experimental layout

[0075] Reference is made to Fig. 5 detailing a preferred embodiment of a generator used to produce the following experimental result. The dimensions indicated in Fig. 5 are given in millimetres. The generator is rotational symmetrical and conforms with a Hartman stem-jet type generator.

[0076] These experiments were carried out with the following layout:

- The Hartmann stem-jet type ultrasound generator was:
    - operating in high-frequency mode, and
    - powered by compressed air, with a consumption of 17 to 33 Nm^3/hr with a working pressure (pressure of the compressed air) range 1.9-3.0 bar(g)
- The Hartmann generator generated
    - an acoustic power between 250-300 W with a generation efficiency between 18 and 25%
    - fundamental generation frequency - 30-32 kHz. The fundamental generation frequency is typically the first harmonic frequency generated since Hartmann generator will produce second, third etc. harmonic frequencies. The acoustic energy content of those higher order harmonics will be orders of magnitude lower than it is of the first (fundamental) one.
    - Sound Pressure Level (SPL) measured at the bottom of a bottle @ 2.5 bar(g) of 157 dB
    - exhaust air flow speed (see 23 in Fig. 3) between 15 and 25 m/s (measured in an exterior distance 10 cm from the generator)

[0077] The generation efficiency is calculated as the ratio of the acoustic power and the power needed to supply the necessary working gas (air) flow to the generator at a working pressure level (1.9-3 bar(g)).

Experiment 1

[0078] Preparation of samples and the experimental procedure:

- Samples were 100-ml-vol molded pulp bottles, wet-formed, dried but uncompressed
- 10 bottle samples were randomly selected for the test
- The 10 samples were conditioned in the laboratory at 23 °C, 50% RH (relative humidity) for 72 hours and weighed
- After weighing, the 10 samples were enumerated and placed in a climate chamber at 23 °C where 100% RH was sustained. Samples remained in the chamber until their weight would increase by ca. 40%
- Two samples were taken from the climate chamber simultaneously for each drying test. Samples with even numbers (2, 4,...,10) remained in the lab at 23 °C, 50% RH during each experiment
- Samples with uneven numbers (1, 3,..., 9) were subjected to a ultrasonic method according to preferred embodiments of the invention
- Each two samples of simultaneously tested samples were weighed every 5 minutes. Each test lasted 25 minutes.

[0079] A measure for the moisture loss is defined as:

$$\Delta M(t) = \frac{W(t) - W_{dry}}{W(0) - W_{dry}}$$

where:

$\Delta M(t)$ is the relative moisture loss at the point in time t
$W(t)$ is the weight of the bottle measured at the point in time t
$W(0)$ is the weight of the bottle right before drying started
W_{dry} is the weight of a conditioned bottle after 72 hours conditioning at 23°C and 50% RH.

[0080] The results from this experiment are shown in Fig. 6 and compared with result obtained by letting samples dry naturally, that is kept in laboratory conditions having a temperature of 23°C and 50% RH with not forced flow in or out of the sample. The naturally dried samples are labelled "without ultrasound" in Fig. 6. The values plotted are averaged value and confidence levels are indicated by vertical lines passing through the average value.

[0081] As illustrated in Fig. 6, the method used according to the invention dramatically decreases the drying time compared to naturally drying. The samples are in average considered to be reach the same weight as W_{dry} at t=17.5 minutes. Thus, as a comparison, the used method dries the samples 253.7 times faster than naturally drying. This comparison is based on bottles naturally dried at 50% RH and 23°C for 74 hours times 60 minutes/hour = 4,440 minutes which gives 4,440/17.5 = 253.7.

Experiment 2

[0082] Preparation of samples and the experimental procedure:

- 12 samples each being a 100-ml-vol molded pulp bottles, wet-formed and thermo-pressed bottle
- The 12 samples were conditioned in the lab at 23 °C, 50% RH for 72 hours and weighed
- The interior surface of the 12 samples were then coated. Six of the samples were dried one by one and weighed every 5 minutes during ultrasonic drying. The remaining six samples were dried in a convection oven at 75°C and weighed every 10 minutes. The ultrasonic drying were carried out as detailed in the above section "Experimental layout"
- The following water-based coatings were used in the experiments:
    - Exceval AQ-4104 (Kuraray), 20% of solids
    - REEF-2 (CelluComp), 33% of solids
    - Vbcoat (Melodea), 43% of solids

[0083] Based on the results, the following fraction was calculated:

$$F_c(t) = \frac{W(t) - W_{uncoated}}{W(t)} 100\%$$

where

$F_c(t)$ is the mass fraction of coating at the point in time t

$W(t)$ is the weight of the bottle measured at the point in time t

$W_{uncoated}$ is the weight of a conditioned bottle after 72 hours conditioning at 23°C and 50% RH, as defined in above Experiment 1.

[0084] The results obtained during this experiment 2 are illustrated in Fig.s 7-9.

[0085] As it appears from the results obtained by the two experiments, use of ultrasonic drying has a very positive effect on reducing the time it take to dry the bottles.

[0086] Results of experiments of ultrasonic drying of bottles coated with water-based barrier coatings clearly indicate that ultrasound can alone (without heating) dry liquid-based coatings only down to a certain residual level of moisture content of the total deposited coating mass. To achieve a complete drying (sintering) of coatings, heat assistance (transfer of thermal energy into the coating layer) may be advantageously applied. The reason for such a stagnation of the ultrasonic drying without heating is that the coatings are usually compounded specifically for providing a high moisture transmission barrier. As soon as the surface and subsurface layers of coatings lose the moisture, the moisture barrier is partially established. This means that the diffusion of moisture from the coating into bottle interior cannot be anymore provided solely by ultrasound assistance (i.e. by turbulization of a diffusion boundary layer and vibrating the bottle wall) and by moisture removal from the bottle interior (by venturi pump/ejection mechanism). Further drying requires heating to facilitate the thermally-stimulated diffusion of moisture from the sub-surface/bulk of the coatings and coated fibers.

ITEMIZED LIST OF PREFERRED EMBODIMENTS

[0087] Item 1. An apparatus for drying a wall of a container (20), comprising

- a generator (1) for generating ultrasonic acoustic waves (16) having:
    - a nozzle (2) comprising an interior flow channel (3) having an inlet (4) and a narrowing section (5) downstream of the inlet (4) and proceeding towards an outlet (6);
    - a resonator (7) comprising a cavity (8) having an open end (9) facing towards said outlet (6) and arranged in a

distance from said outlet (6);

◦ a stem (10) having a diameter being less than a diameter of said outlet (6), said stem (10) arranged co-axially with a longitudinal axis of said narrowing section (2) and extending from a bottom of said cavity (8) through said outlet (6) and at least to a position inside said flow channel (3) being upstream of said narrowing section(5);

- an acoustic waveguide (11) configured to guide acoustic waves generated by said generator into an interior of an associated container, said waveguide comprising a tubular element being

◦ dimensioned to accommodate at least a section of said nozzle (2) comprising said narrowing section (5) and to accommodate said resonator (7) with a clearance (12) providing a flow path between an inner wall of said tubular element (12) and said section of said nozzle (2) and said resonator (7), and

◦ configured to receive at least a part of a mouth section (21) of said associated container in a position being distal from said resonator (7).

[0088] Item 2. An apparatus according to item 1, wherein the generator is a stem-jet Hartmann type generator.

[0089] Item 3. An apparatus according to any one of the preceding items, wherein said cavity (8) has a depth (*h*) and wherein said resonator (7) is arranged in a distance (*l*) evaluated between said outlet (6) and said open end (9) so that the sum of said depth (*h*) and said distance (*l*), during use, is larger than 1.3 times a shock cell length (Δ_0) and smaller than 2.0 times said shock cell length (Δ_0).

[0090] Item 4. An apparatus according to any one of the preceding items, wherein exterior dimensions of said section of said nozzle (2) and said resonator (7), and interior dimension of said acoustic waveguide (11) are mutually configured to provide said clearance (12) with cross sectional area allowing for sucking-in of exterior flow, and extraction of gas from the interior of the container.

[0091] Item 5. An apparatus according to any one of the preceding items, wherein the distance between the outlet (6) and the open end of the cavity (9) is adjustable by the stem (10) being slidable in a longitudinal direction of the stem, so as to allow for a longitudinal movement of the stem (6) while still allowing for fixation of longitudinal position of the stem (6).

[0092] Item 6. An apparatus according to any one of the preceding items, wherein the apparatus comprising one or more heat sources configured for providing an elevated temperature in heating region downstream of said tubular element (12) and into which said ultrasonic acoustic waves (16) propagates.

[0093] Item 7. An apparatus according to item 5, wherein said heat source(s) is(are) configured to transfer heat by contact heating, convection heating and/or radiation heating.

[0094] Item 8. An apparatus according to item 5 or 6, wherein said one or more heat sources comprises electrical heaters, such as ohmic heaters, radio-frequency electromagnetic waves, in particular microwaves, based heater, microwaves heaters, Peltier elements, infra-red radiation sources.

[0095] Item 9. An apparatus according to any one of the preceding items, wherein said apparatus further comprising a pressurised gas source (17), configured to provide a flow of pressurized gas with a pressure being larger than 1.9 bar(g) and smaller than 3.0 bar(g).

[0096] Item 10. An apparatus according to item 9, wherein said pressurised gas source (17) is configured to provide an amount of pressurised gas in the range of 15-35 Nm^3/hr.

[0097] Item 11. An apparatus according to item 9 or 10, wherein said pressurised gas source (17) comprising a compressor.

[0098] Item 12. An apparatus according to any one of items 8-11, wherein said gas is atmospheric air, helium, argon, nitrogen, or super heated steam.

[0099] Item 13. An apparatus according to any one of the preceding items, wherein said tubular element (12) is configured to receive said mouth section (21) comprising an internal thread.

[0100] Item 14. An apparatus according to any one of the preceding items, wherein said narrowing section (5), said cavity (8) and at least a section of said stem (10) extending through said outlet (6) are rotational symmetric.

[0101] Item 15. A method of drying a container, the method utilizes an apparatus according to any one of the preceding items, comprising

- providing a wet-moulded paper container or a dry-moulded container having an interior liquid coating, where said container has a mouth section,
- receiving at least a section of said mouth section (21) of said container in said tubular element (12), and
- feeding pressurized gas into said inlet (4).

[0102] Item 16. A method according to item 15, wherein said the pressure and volume flow of said pressurized gas are selected to provide ultrasonic acoustic waves having a first harmonic frequency between 30-32 kHz and a sound pressure level, preferably measured at a bottom of the container, larger than 157 dB.

[0103] Item 17. A method according to item 15 or 16, wherein the pressure of said gas has a pressure between 1.9 bar (g) and 3.0 bar (g).

[0104] Item 18. A method according to any one of items 15-17, wherein a/the volume flow of said pressurized gas is selected between 15 and 25 Nm^3 (normal cubic meters) pressure between 1.9 and 3.0 bar(g).

[0105] Item 19. A method according to any one of the preceding items, wherein the temperature of said gas is larger than 15°C, such as larger than 20°C, and smaller than 50°C, such as smaller than 40°C.

[0106] Item 20. A method according to any one of the preceding items 15-19, wherein the method is carried out in an atmosphere exterior to the container, wherein said pressurized gas fed into said inlet (4) is(are) gas(ses) of said exterior atmosphere.

[0107] Item 21. A method according to any one of the preceding items 15-20, wherein said gas is atmospheric air, preferably having a relative humidity less than 50% RH at 22°C.

[0108] Item 22. A method according to item 21, wherein said atmospheric air prior to pressurization is untreated atmospheric air, and the pressurized air is only treated to remove detritus and/or oil contamination originating from the pressurization prior to being fed into said inlet (4).

[0109] Item 23. A method according to any one of the preceding items 20-22, wherein the container is a wet-moulded paper bottle or a dry-molded paper bottle having an interior liquid coating said wet-moulded paper bottle or dry-molded paper bottle being produced from cellulose fibre, including paper pulp.

[0110] Although the present invention has been described in connection with the specified embodiments, it should not be construed as being in any way limited to the presented examples. The scope of the present invention is to be interpreted in the light of the accompanying claim set. In the context of the claims, the terms "comprising" or "comprises" do not exclude other possible elements or steps. Also, the mentioning of references such as "a" or "an" etc. should not be construed as excluding a plurality. The use of reference signs in the claims with respect to elements indicated in the figures shall also not be construed as limiting the scope of the invention. Furthermore, individual features mentioned in different claims, may possibly be advantageously combined, and the mentioning of these features in different claims does not exclude that a combination of features is not possible and advantageous..

List of reference symbols used

[0111]

1 Generator
2 Nozzle
3 Interior flow channel
4 Inlet
5 Narrowing section
6 Outlet
7 Resonator
8 Cavity
9 Open end
10 Stem
11 Acoustic waveguide
12 Clearance
13 Air inflow
14 Acoustic turbulent boundary layer
15 Effusion
16 Ultrasonic acoustic wave
17 Pressurized air source
18 Bottom (of cavity 8)
19 Interior air flow
20 Container
21 Mouth section
22 Interior recess
23 Exhaust air flow
24 Gas (air) inflow
25 Reversed flow

h Depth of cavity 8
l distance evaluated between outlet 6 and open end 9

Δ_0 Shock cell length

Claims

1. An apparatus for drying a wall of a container (20), comprising

   - a generator (1) for generating ultrasonic acoustic waves (16) having:

     ◦ a nozzle (2) comprising an interior flow channel (3) having an inlet (4) and a narrowing section (5) downstream of the inlet (4) and proceeding towards an outlet (6);
     ◦ a resonator (7) comprising a cavity (8) having an open end (9) facing towards said outlet (6) and arranged in a distance from said outlet (6);
     ◦ a stem (10) having a diameter being less than a diameter of said outlet (6), said stem (10) arranged co-axially with a longitudinal axis of said narrowing section (2) and extending from a bottom of said cavity (8) through said outlet (6) and at least to a position inside said flow channel (3) being upstream of said narrowing section(5);

   - an acoustic waveguide (11) configured to guide acoustic waves generated by said generator into an interior of an associated container, said waveguide comprising a tubular element being

     ◦ dimensioned to accommodate at least a section of said nozzle (2) comprising said narrowing section (5) and to accommodate said resonator (7) with a clearance (12) providing a flow path between an inner wall of said tubular element (12) and said section of said nozzle (2) and said resonator (7), and
     ◦ configured to receive at least a part of a mouth section (21) of said associated container in a position being distal from said resonator (7).

2. An apparatus according to claim 1, wherein said cavity (8) has a depth (*h*) and wherein said resonator (7) is arranged in a distance (*l*) evaluated between said outlet (6) and said open end (9) so that the sum of said depth (*h*) and said distance (*l*), during use, is larger than 1.3 times a shock cell length (Δ_0) and smaller than 2.0 times said shock cell length (Δ_0).

3. An apparatus according to claim 1 or 2, wherein exterior dimensions of said section of said nozzle (2) and said resonator (7), and interior dimension of said acoustic waveguide (11) are mutually configured to provide said clearance (12) with cross sectional area allowing for sucking-in of exterior flow, and extraction of gas from the interior of the container.

4. An apparatus according to any one of the preceding claims, wherein the apparatus comprising one or more heat sources configured for providing an elevated temperature in heating region downstream of said tubular element (12) and into which said ultrasonic acoustic waves (16) propagates.

5. An apparatus according to any one of the preceding claims, wherein said apparatus further comprising a pressurised gas source (17), configured to provide a flow of pressurized gas with a pressure being larger than 1.9 bar(g) and smaller than 3.0 bar(g).

6. An apparatus according to any one of claim 5, wherein said gas is atmospheric air, helium, argon, nitrogen, or super heated steam.

7. An apparatus according to any one of the preceding claims, wherein said tubular element (12) is configured to receive said mouth section (21) comprising an internal thread.

8. A method of drying a container, the method utilizes an apparatus according to any one of the preceding claims, comprising

   - providing a wet-moulded paper container or a dry-moulded container having an interior liquid coating, where said container has a mouth section,
   - receiving at least a section of said mouth section (21) of said container in said tubular element (12), and
   - feeding pressurized gas into said inlet (4).

9. A method according to claim 8, wherein said the pressure and volume flow of said pressurized gas are selected to provide ultrasonic acoustic waves having a first harmonic frequency between 30-32 kHz and a sound pressure level, preferably measured at a bottom of the container, larger than 157 dB.

10. A method according to claim 8 or 9, wherein the pressure of said gas has a pressure between 1.9 bar (g) and 3.0 bar (g).

11. A method according to any one of claims 8-10, wherein a/the volume flow of said pressurized gas is selected between 15 and 25 Nm^3 (normal cubic meters) pressure between 1.9 and 3.0 bar(g).

12. A method according to any one of the preceding claims 8-11, wherein the method is carried out in an atmosphere exterior to the container, wherein said pressurized gas fed into said inlet (4) is(are) gas(ses) of said exterior atmosphere.

13. A method according to any one of the preceding claims 8-12, wherein said gas is atmospheric air, preferably having a relative humidity less than 50% RH at 22°C.

14. A method according to claim 13, wherein said atmospheric air prior to pressurization is untreated atmospheric air, and the pressurized air is only treated to remove detritus and/or oil contamination originating from the pressurization prior to being fed into said inlet (4).

15. A method according to any one of the preceding claims 8-14, wherein the container is a wet-moulded paper bottle or a dry-molded paper bottle having an interior liquid coating said wet-moulded paper bottle or dry-molded paper bottle being produced from cellulose fibre, including paper pulp.

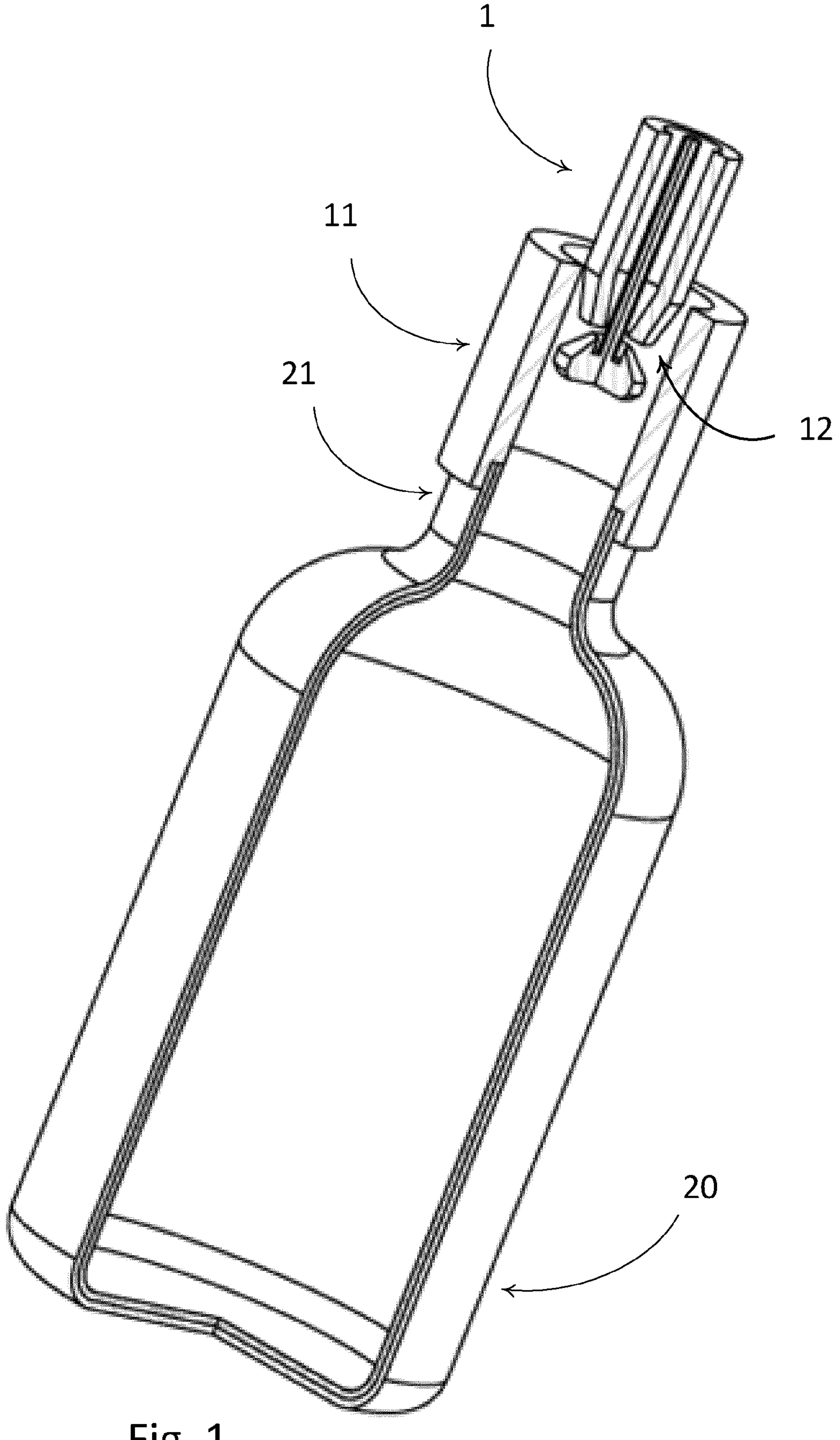

Fig. 1

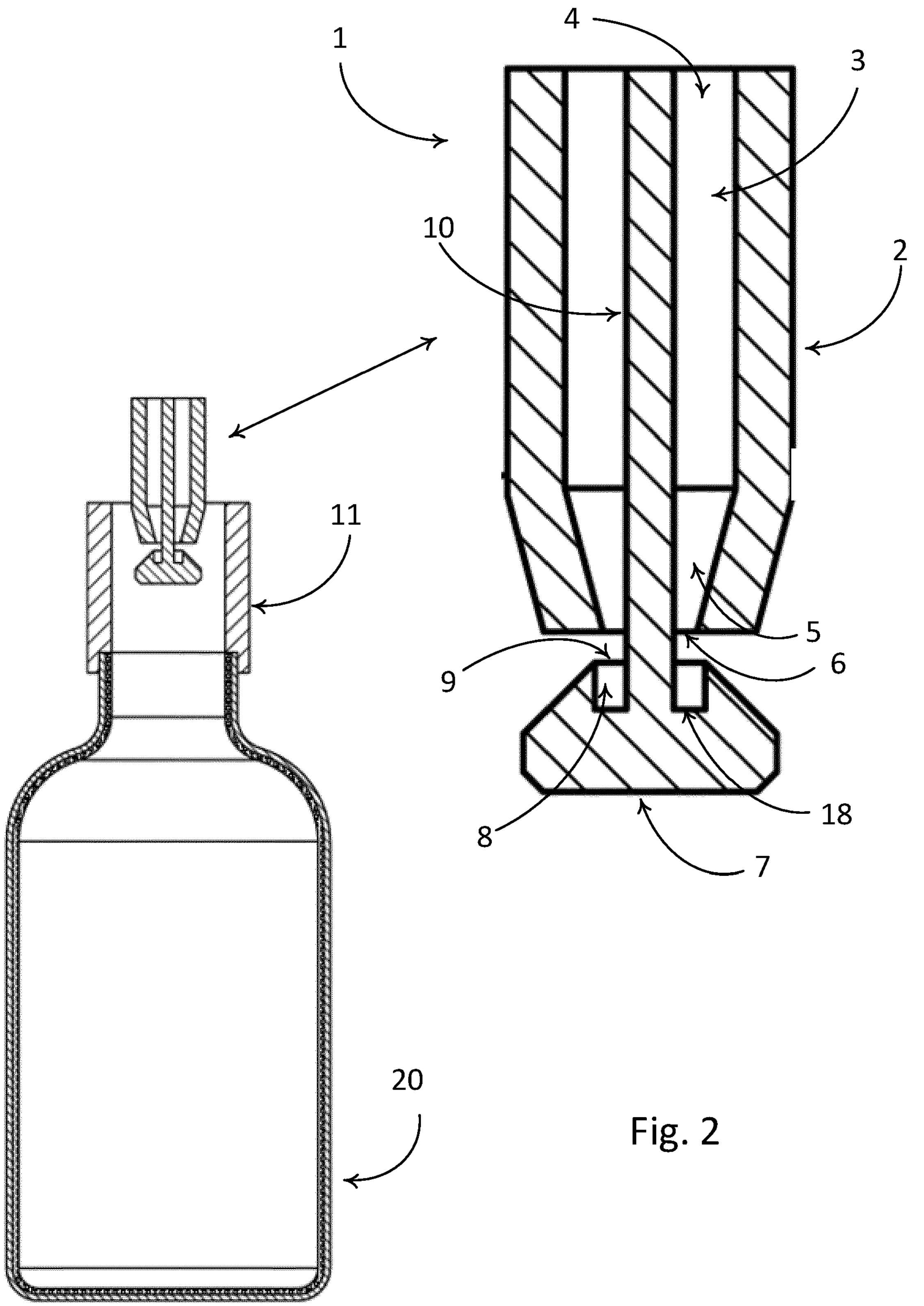

Fig. 2

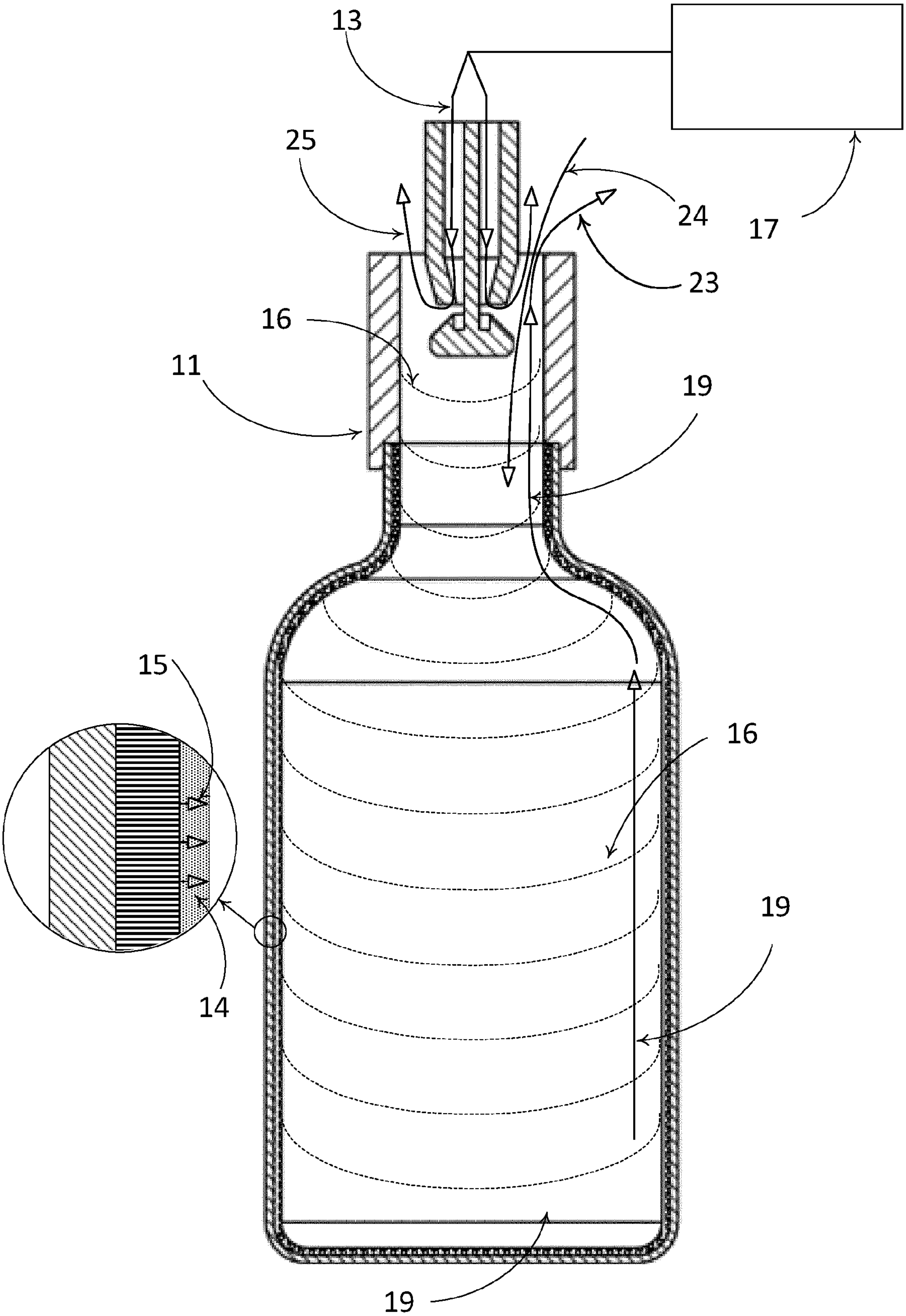

Fig. 3

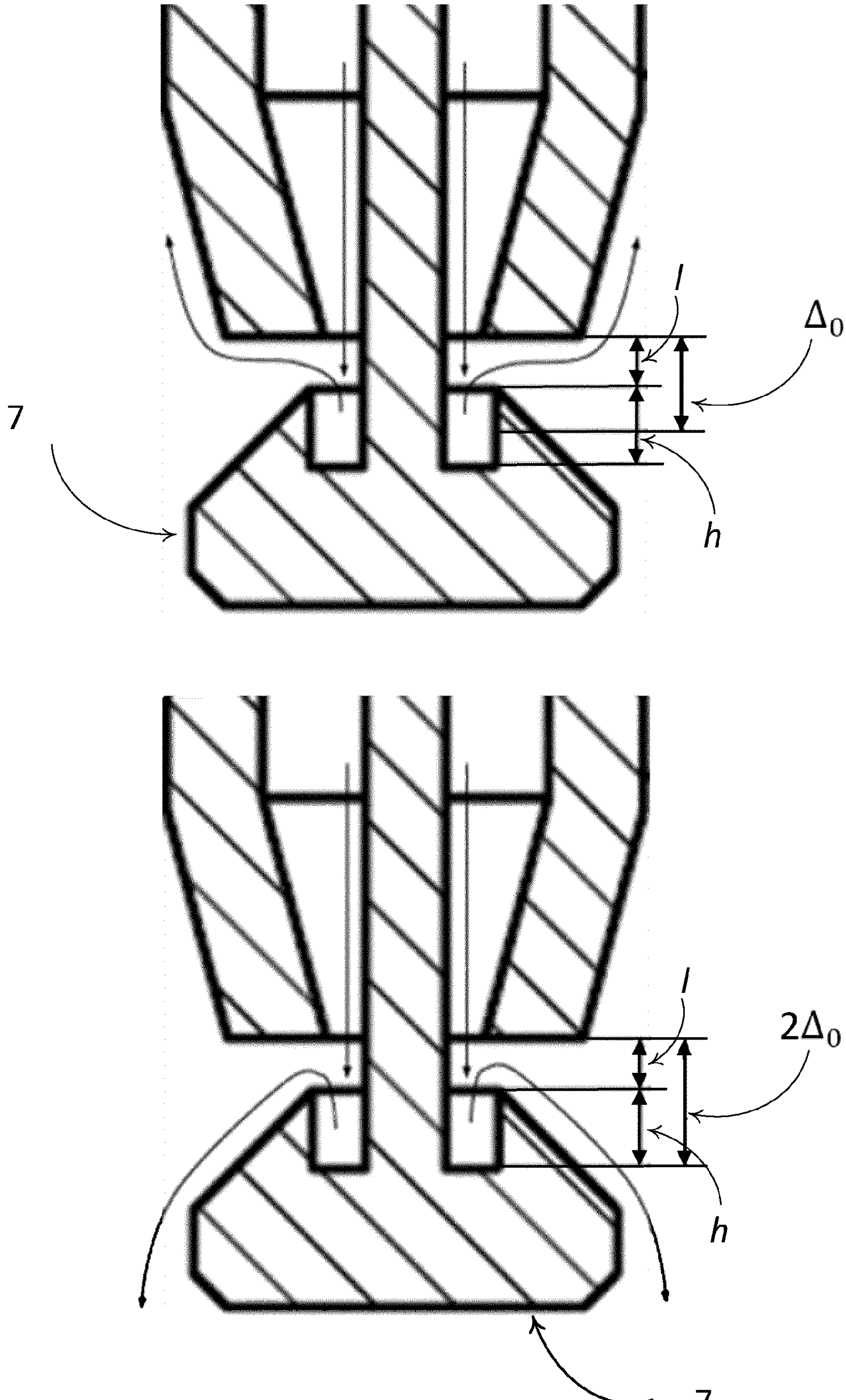

Fig. 4

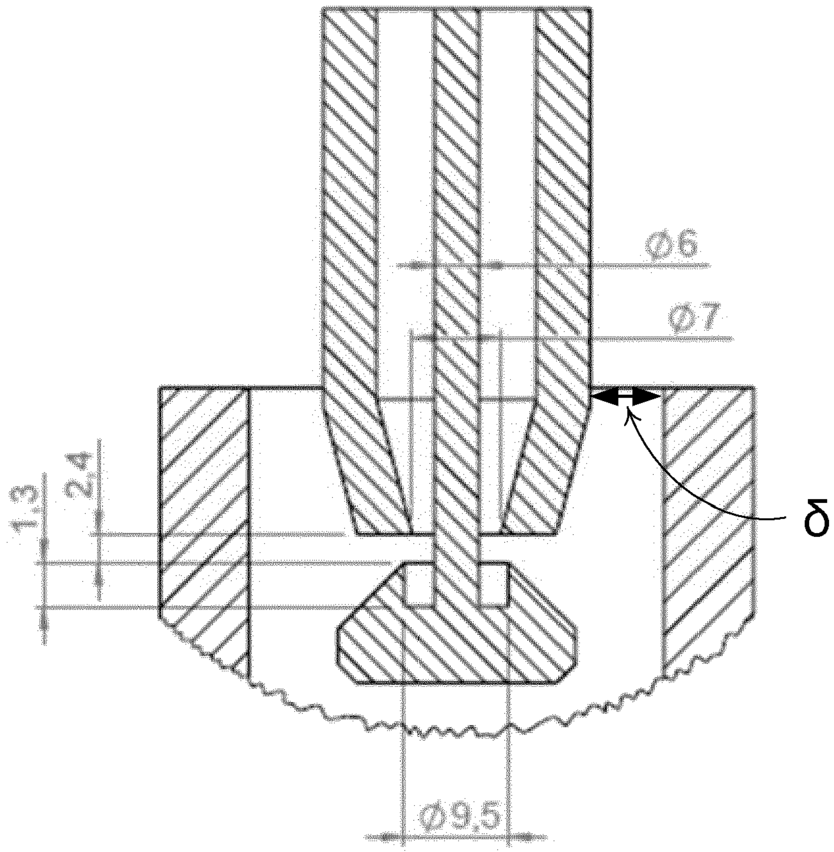

Fig. 5

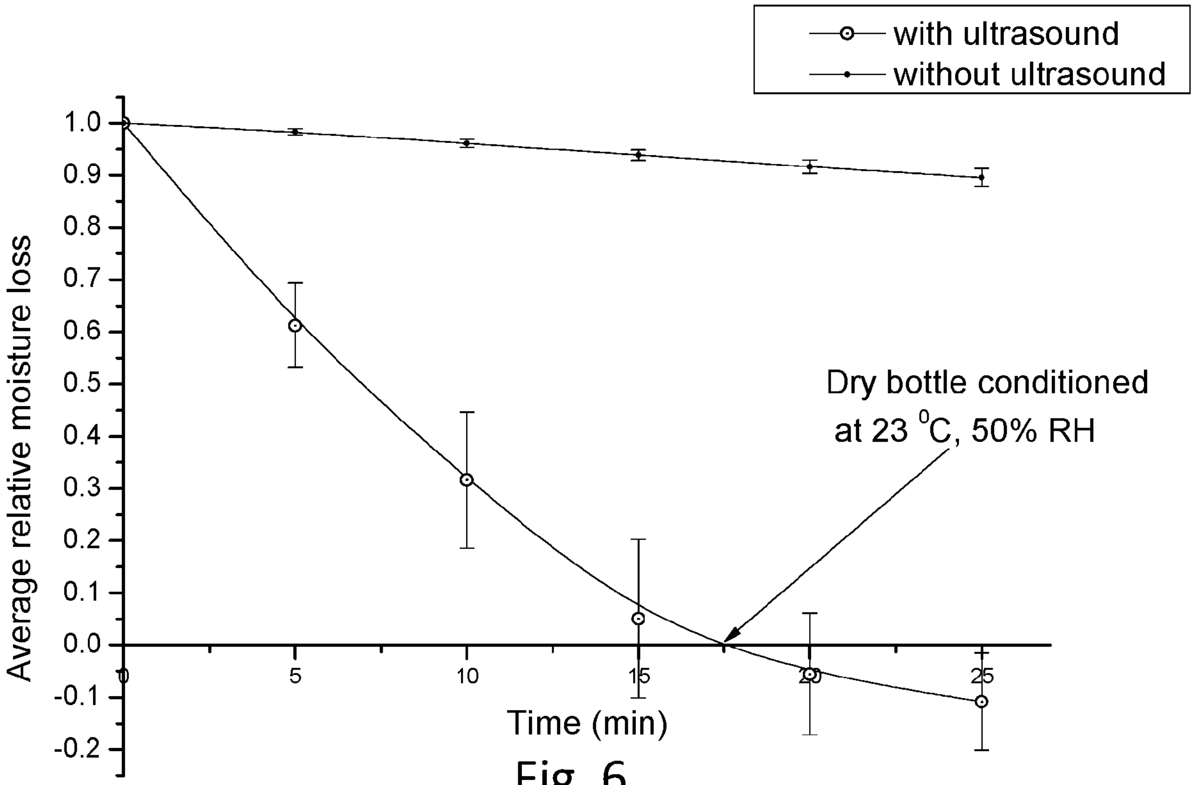
with ultrasound
without ultrasound
Average relative moisture loss
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
0
5
10
15
20
25
Time (min)
Dry bottle conditioned
at 23 °C, 50% RH

Fig. 6

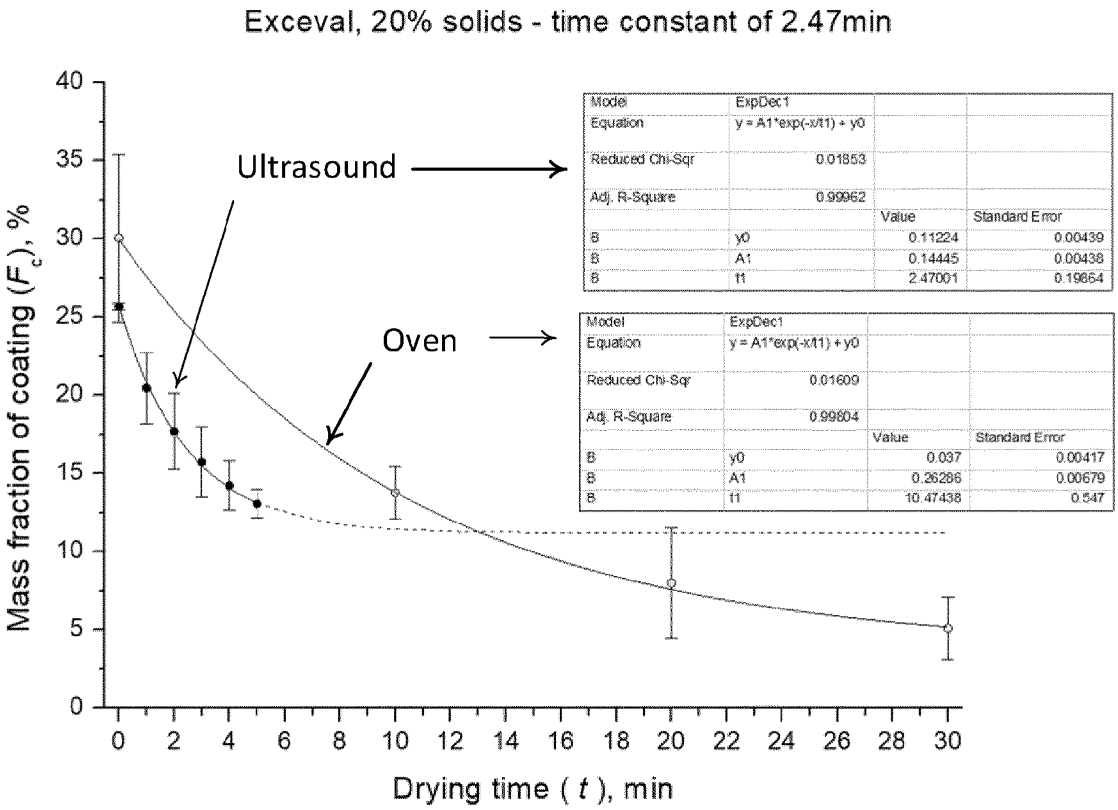
Exceval, 20% solids - time constant of 2.47min
Mass fraction of coating (F_c), %
Drying time (t), min
Ultrasound
Oven
Model | ExpDec1
Equation | y = A1*exp(-x/t1) + y0
Reduced Chi-Sqr | 0.01853
Adj. R-Square | 0.99962
Value | Standard Error
B | y0 | 0.11224 | 0.00439
B | A1 | 0.14445 | 0.00438
B | t1 | 2.47001 | 0.19864
Model | ExpDec1
Equation | y = A1*exp(-x/t1) + y0
Reduced Chi-Sqr | 0.01609
Adj. R-Square | 0.99804
Value | Standard Error
B | y0 | 0.037 | 0.00417
B | A1 | 0.26286 | 0.00679
B | t1 | 10.47438 | 0.547

Fig. 7

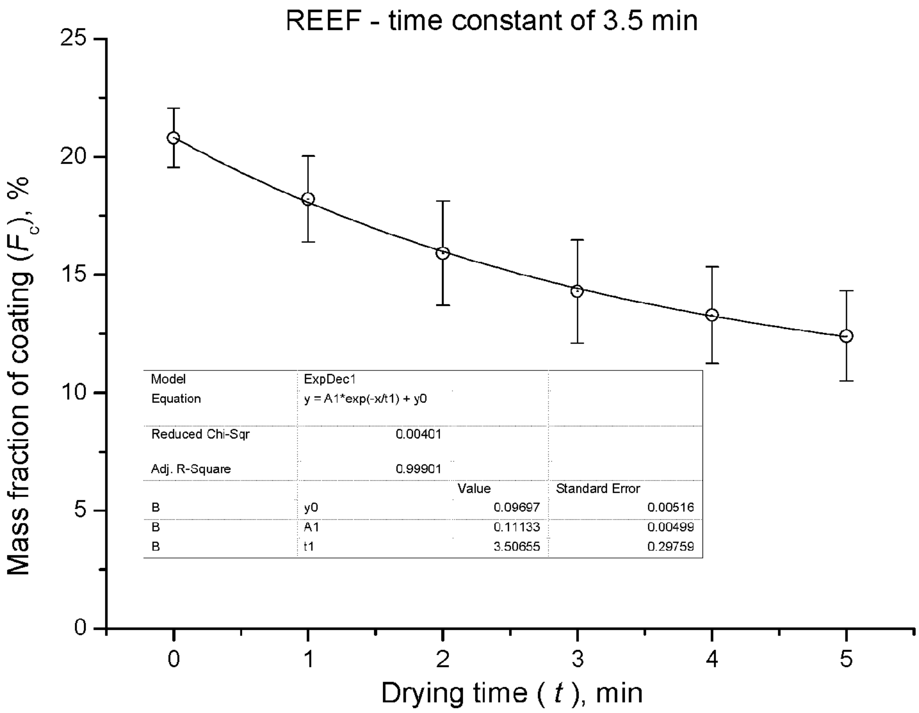
REEF - time constant of 3.5 min
Mass fraction of coating (F_c), %
Drying time (t), min
Model
ExpDec1
Equation
y = A1*exp(-x/t1) + y0
Reduced Chi-Sqr
0.00401
Adj. R-Square
0.99901
Value
Standard Error
B
y0
0.09697
0.00516
B
A1
0.11133
0.00499
B
t1
3.50655
0.29759

Fig. 8

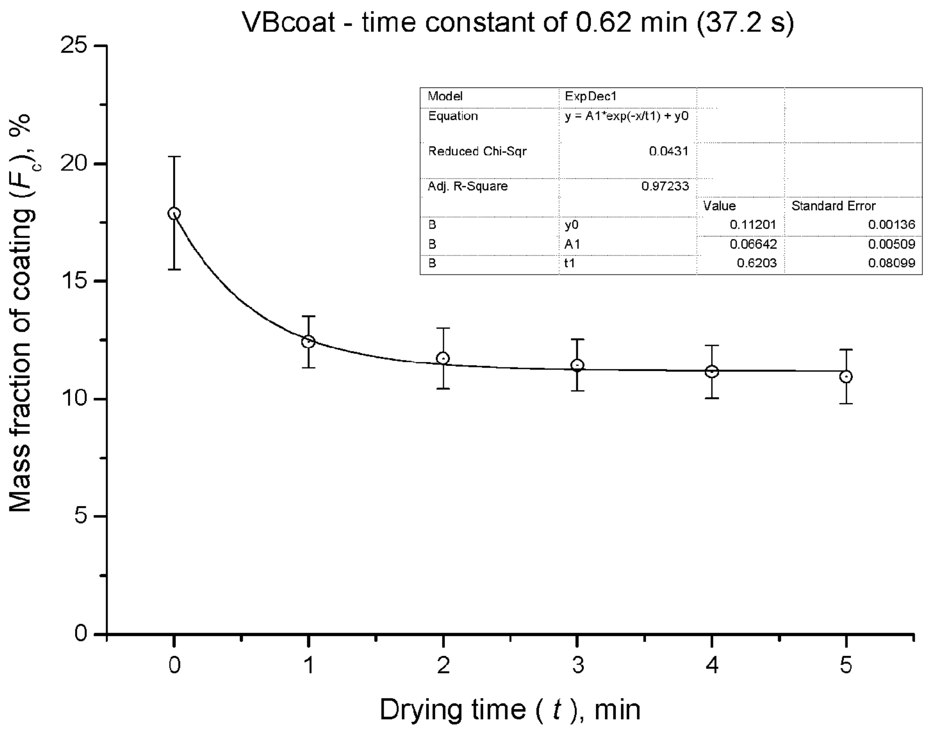
VBcoat - time constant of 0.62 min (37.2 s)
Mass fraction of coating (F_c), %
Drying time (t), min
Model
ExpDec1
Equation
y = A1*exp(-x/t1) + y0
Reduced Chi-Sqr
0.0431
Adj. R-Square
0.97233
Value
Standard Error
B
y0
0.11201
0.00136
B
A1
0.06642
0.00509
B
t1
0.6203
0.08099

Fig. 9

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EUROPEAN SEARCH REPORT

Application Number
EP 23 21 5902

DOCUMENTS CONSIDERED TO BE RELEVANT

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The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	30 April 2024	Makúch, Milan

CATEGORY OF CITED DOCUMENTS

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30-04-2024

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