

Title

A method and an embossing set-up to emboss turbulence producing features into a sheet of material for an inhalable drug delivery system's filtering element

Technical field of invention

The invention is in the field of manufacturing for the inhalable drug delivery system industry, including smoking products in which medical drugs or nicotine may be dispensed in a gas to a user in various inhalable ways, comprising for example vapor, heated tobacco, and conventional burned tobacco as known from cigarettes and cigars, more specifically in a field of embossing, and relating to a component of a filtering element.

Background of the invention

Numerous prior art references discuss the technical field of the invention specifically for the cigarette industry.

Prior art publication "Basic principle of cigarette design and Function" by Ken Podraza, Philip Morris, Presentation to LSRO 29-30 October 2001 contains a wealth of information about the parameters ruling the manufacturing and the consumption of cigarettes.

A further prior art publication "Effect of cigarette filter components on its efficiency and smoking characteristic of cigarettes", Sobhy Mohammed Mohsen, Abdalla S.M. Ammar, Ateya Fathy, Bioscience Research, January 2018, Pages 325–336, is a further source of information more focused on cigarette filters of cigarettes.

French publication FR 2 418 628 discusses a method and a device for transforming a fibrous sheet of material in order to manufacture a cigarette filter or simple filter. The publication describes how to make a certain topographical profile on the sheet to obtain a filtering structure, whereby the height of the profile may be varied during the process, to vary at the same time a transversal stretching of the sheet, and hence its texture's characteristics, to obtain on one hand an embossed texture or on the other hand a longitudinal creped texture, or any intermediate texture, whereby the characteristics may be varied without any discontinuity. Hence the draft of the resulting filter may be adjusted as needed by suitably adapting the texture.

Since the publications of above prior art documents, smoking and other inhalable drug delivery systems have undergone significant development with a recent multiplication of utilization domains. In addressing an enhanced user experience, much research and development has been centred around the filtering element of a such a device, which currently primarily serves the purpose of filtering the gas generated from the drug containing part of the inhalable drug delivery system. The user then receives a mainstream gas into his mouth by drawing through the filter on the opposite end of the cigarette. Certain cigarettes or other inhalable drug delivery systems incorporate filter elements or towels having absorbent materials dispersed therein, such as activated carbon or charcoal materials in particulate or granular form. For example, a filtering element can possess multiple segments, and at least one of those segments can comprise particles of high carbon-content materials.

Following facts may be retrieved from the reading of both above cited prior art documents "Basic principle of cigarette design and Function" and "Effect of cigarette filter components on its efficiency and smoking characteristic of cigarettes":

Paper cigarette filters offer a higher smoke-component removal efficiency as the conventional cellulose acetate cigarette filters, at a same filter characteristic pressure drop, but this increase comes with a poor visual appearance. A filter pressure drop is the amount of suction that must be used to pull smoke through the filter, at a standardized suction volume (35 ml puff in 2s).

The term "Retention", used at further points in the description of this invention, is alternative way of designating a filtering efficiency, i.e., a percentage of gas components (e.g., particulates) that are removed by the filtering element.

As the pressure drop increases for a given filtering configuration, filtration efficiency increases due to a reduction in a mainstream gas velocity. In the same time, particulate phase materials can be removed to some degree with a filtering element produced of fibrous materials, while gases (CO, NOx) are not removed.

Considering its dynamics, a gas flow velocity shall increase as the gas passes through a constriction section, whereas its static pressure shall decrease in accord with the principle of conservation of mechanical energy (Bernoulli's principle). Thus, any gain in kinetic energy a gas may attained by its increased velocity through a constriction section is balanced by a drop in pressure.

As Bernoulli's principle is invertible, by passing through an expansion section the gas flow velocity shall decrease and its static pressure should rise. Furthermore, if a gas flow presents an alternance of a constriction section and an expansion section, turbulences will appear in the gas flow.

Departing from prior art knowledge, the invention aims at providing a method and an embossing set-up to manufacture a novel embossed sheet of material configured to be folded to obtain a filter element which constitutes an alternative to existing technology, and is applicable for a inhalable drug delivery system in general.

Summary of the invention

In a first aspect, the invention provides a method for manufacturing an embossed sheet of material configured to be folded and obtain a filtering element configured for an inhalable drug delivery device, and for filtering a mainstream gas flow passing through the filtering element. The method comprises steps of: providing the sheet of material; and embossing the sheet of material with a plurality of stripes, by means of a patrix-matrix embossing rollers system, and by feeding the sheet of material to a nip between the patrix-matrix embossing rollers, each stripe comprising corresponding embossing features on each of a patrix embossing roller and a matrix embossing roller of the embossing rollers system, and each embossed stripe being oriented longitudinally on the sheet of material with respect to a feed direction of the sheet of material fed to the nip. The embossing features comprise: profile embossing features configured for embossing at least an aerodynamic profile on the sheet of material, the profile embossing features being arranged according to a radial direction of the stripe on the embossing rollers, the embossed aerodynamic profile being configured to modify in a determined manner flow properties for the mainstream gas flow passing through the filtering element by creating a gas flow turbulence occurrence in the filtering element, whereby the profile embossing features in the stripe form at least an alternance of a minimum constriction section area and a maximum expansion section area in the radial direction of the stripe on the embossing roller, with a cross-section area ratio between the maximum expansion section area and the minimum constriction section area in a range from 15:1 to 2:1. The embossing features further comprise: radial embossing features configured to delimitate each stripe on opposite radial sides of the stripe, on the patrix-matrix embossing rollers, and further configured to form longitudinal delimitation embossed features that delimitate the embossed stripe on the sheet of material, on opposite longitudinal sides of the embossed stripe.

In a preferred embodiment, the radial embossing features are further configured to emboss a folding line into the sheet of material.

In a further preferred embodiment, the radial embossing features are further configured to form a plurality of enclosing walls on the matrix embossing rollers describing at least an enclosure around one or a plurality of the profile embossing features, and, for each enclosure, an enclosure opening in the enclosure connecting the enclosure to a successive enclosure in radial direction of the stripe, the enclosure having a corresponding maximum enclosure expansion section area in axial direction of the stripe and the enclosure opening having a corresponding enclosure opening constriction section area in the axial direction of the stripe which is smaller than the corresponding maximum enclosure expansion section area. The radial embossing features are further configured to define at least one alternance of the enclosure opening constriction section area and the maximum enclosure expansion section area in the longitudinal direction of the stripe, formed by the enclosure opening and the enclosure respectively, with a cross-section area ratio between the maximum enclosure expansion section area and the enclosure opening constriction section area of the profile in a range from 15:1 to 2:1.

In a further preferred embodiment, a first set of the profile embossing features in a first one of the stripes is designed for a determined gas flow turbulence in a first longitudinal direction of a corresponding embossed first one of the stripes, and a second set of the profile embossing features in a second one of the stripes adjacent to the first one is designed for the determined gas flow turbulence in a second longitudinal direction of a corresponding embossed second one of the stripes, opposite to the first longitudinal direction.

In a further preferred embodiment, the profile embossing features comprise at least one from a list comprising a recess profile embossing feature configured to emboss a corresponding recessed shape in the sheet of material and at least a protrusion profile embossing feature configured to emboss a corresponding protrusion in the sheet of material.

In a further preferred embodiment, the sheet of material comprises any material from a list comprising paper, a cellulose-based material, wool, plant- or animal-based fibrous material.

In a further preferred embodiment, the profile embossing features are further configured to produce a height of the aerodynamic profile that is in a range of 1 to 15 times of a thickness of the sheet of material.

In a further preferred embodiment, the embossing of the sheet of material is configured to be a wallpaper-like embossing producing an uninterrupted and repeating pattern of embossed aerodynamic features and longitudinal delimitation embossed features.

In a further preferred embodiment, the cross-section area ratio between the maximum expansion section area and the minimum constriction section area is in a range of 8:1 to 3:1.

In a further preferred embodiment, one alternance of two successive enclosure opening constriction sections (p) has a length equal or smaller than 40 mm.

In a further preferred embodiment, the one alternance of two successive enclosure opening constriction sections (p) is preferably between 3 mm and 30 mm.

In a further preferred embodiment, the profile embossing features further comprise a plurality of baffle embossing features enabling the embossed aerodynamic profile to enhance the gas flow turbulence occurring in at least one of the maximum expansion section areas in an alternance of the maximum expansion section area and the minimum constriction section area, whereby the plurality of baffle embossing features are embossed successively in longitudinal direction.

In a further preferred embodiment, each one of the profile embossing features as a height in a range between 0,1 mm and 2,5 mm.

In a further preferred embodiment, each one of the plurality of baffle embossing features are either one of a protrusion and a recess feature, whereby heights in case of protrusion features, or depths in case of recess features are in a range between 0,1 mm and 2 mm.

In a further preferred embodiment, the sheet of material has a grammage in a range between 10 gsm and 100 gsm and a thickness in a range between 0,02 mm and 1,5 mm.

In a second aspect, the invention provides an embossing set-up for manufacturing an embossed sheet of material configured to be folded and obtain a filtering element configured for an inhalable drug delivery device, and for filtering a mainstream gas flow passing through the filtering element. The embossing set-up comprises features of a patrix-matrix roller embossing system configured to emboss the sheet of material with a plurality of stripes, in a nip between the patrix-matrix embossing rollers, each stripe comprising corresponding embossing features on each of a patrix embossing roller and a matrix embossing roller of the embossing rollers system, and each embossed stripe being oriented longitudinally on the sheet of material with respect to a feed direction of the sheet of material fed to the nip. The embossing features comprise profile embossing features configured for embossing at least an aerodynamic profile on the sheet of material, the profile embossing features being arranged according to a radial direction of the stripe on the embossing rollers, the embossed aerodynamic profile being configured to modify in a determined manner flow properties for the mainstream gas flow passing through the filtering element by creating a gas flow turbulence occurrence in the filtering element; whereby the profile embossing features in the stripe form at least an alternance of a minimum constriction section area and a maximum expansion section area in the radial direction of the stripe on the embossing roller, with a cross-section area ratio between the maximum expansion section area and the minimum constriction section area in a range from 15:1 to 2:1. The embossing features further comprise radial embossing features configured to delimitate each stripe on opposite radial sides of the

stripe, on the matrix-embossing rollers, and further configured to form longitudinal delimitation embossed features that delimitate the embossed stripe on the sheet of material, on opposite longitudinal sides of the embossed stripe.

In a further preferred embodiment, the radial embossing features are further configured to emboss a folding line into the sheet of material.

In a further preferred embodiment, the radial embossing features are further configured to form a plurality of enclosing walls on the matrix-embossing rollers describing at least an enclosure around one or a plurality of the profile embossing features, and, for each enclosure, an enclosure opening in the enclosure connecting the enclosure to a successive enclosure in radial direction of the stripe, the enclosure having a corresponding maximum enclosure expansion section area in axial direction of the stripe and the enclosure opening having a corresponding enclosure opening constriction section area in the axial direction of the stripe which is smaller than the corresponding maximum enclosure expansion section area, and to define at least one alternance of the enclosure opening constriction section area and the maximum enclosure expansion section area in the longitudinal direction of the stripe, formed by the enclosure opening and the enclosure respectively, with a cross-section area ratio between the maximum enclosure expansion section area and the enclosure opening constriction section area of the profile in a range from 15:1 to 2:1.

In a further preferred embodiment, a first set of the profile embossing features in a first one of the stripes is designed for a determined gas flow turbulence in a first longitudinal direction of a corresponding embossed first one of the stripes, and a second set of the profile embossing features in a second one of the stripes adjacent to the first one is designed for the determined gas flow turbulence in a second longitudinal direction of a corresponding embossed second one of the stripes opposite to the first longitudinal direction.

In a further preferred embodiment, the profile embossing features comprise at least one from a list comprising a recess profile embossing feature configured to emboss a corresponding recessed shape in the sheet of material and a protrusion profile embossing feature configured to emboss a corresponding protrusion in the sheet of material.

In a further preferred embodiment, the sheet of material comprises any material from a list comprising paper, a cellulose-based material, wool, plant- or animal-based fibrous material.

In a further preferred embodiment, the profile embossing features are further configured to produce a height of the aerodynamic profile that is in a range of 1 to 15 times of a thickness of the sheet of material.

In a further preferred embodiment, the patrix-matrix rollers and the embossing features are configured for embossing of the sheet of material to be a wallpaper-like embossing producing an uninterrupted and repeating pattern of embossed aerodynamic features and longitudinal delimitation embossed features.

In a further preferred embodiment, the cross-section area ratio between the maximum expansion section area and the minimum constriction section of the profile is in a range of 8:1 to 3:1.

In a further aspect, the invention provides a method for manufacturing an embossed sheet of material configured to be folded and obtain a filtering element configured for an inhalable drug delivery device, and for filtering a mainstream gas flow passing through the filtering element. The method comprises steps of providing the sheet of material; and embossing the sheet of material with a plurality of stripes, by means of a patrix-matrix embossing rollers system, and by feeding the sheet of material to a nip between the patrix-matrix embossing rollers, each stripe comprising corresponding embossing features on each of a patrix embossing roller and a matrix embossing roller of the embossing rollers system, and each embossed stripe being oriented longitudinally on the sheet of material with respect to a feed direction of the sheet of material fed to the nip. The embossing features comprises profile embossing features configured for embossing at least an aerodynamic profile on the sheet of material, the profile embossing features being arranged according to a radial direction of the stripe on the embossing rollers, the embossed aerodynamic profile being configured to modify in a determined manner flow properties for the mainstream gas flow passing through the filtering element by creating a gas flow turbulence occurrence in the filtering element; and the embossing features further comprises radial embossing features configured to delimitate each stripe on opposite radial sides of the stripe, on the patrix-matrix embossing rollers, and further configured to form longitudinal delimitation embossed features that delimitate the embossed stripe on the sheet of material, on opposite longitudinal sides of the embossed stripe. The radial embossing features are further configured to form a plurality of enclosing walls on the patrix-matrix embossing rollers describing at least an enclosure around one or a plurality of the profile embossing features, and, for each enclosure, an enclosure opening in the enclosure connecting the enclosure to a successive enclosure in radial direction of the stripe, the enclosure having a corresponding maximum enclosure expansion section area in axial direction of the stripe and the enclosure opening having a corresponding enclosure opening constriction section area in the axial direction of the stripe which is smaller than the corresponding maximum enclosure expansion section area. The radial embossing features are further configured to define at least one alternance of the enclosure opening constriction section area and the maximum enclosure expansion section area in the longitudinal direction of the stripe, formed by the enclosure opening and the enclosure respectively, with a cross-section area ratio between the maximum enclosure expansion section area and the enclosure opening constriction section area of the profile in a range from 15:1 to 2:1.

In a further preferred embodiment, the radial embossing features are further configured to emboss a folding line into the sheet of material.

In a further preferred embodiment, a first set of the profile embossing features in a first one of the stripes is designed for a determined gas flow turbulence in a first longitudinal direction of a corresponding embossed first one of the stripes, and a second set of the profile embossing features in a second one of the stripes adjacent to the first one is designed for the determined gas flow turbulence in a second longitudinal direction of a corresponding embossed second one of the stripes, opposite to the first longitudinal direction.

In a further preferred embodiment, the profile embossing features comprise at least one from a list comprising a recess profile embossing feature configured to emboss a corresponding recessed shape in the sheet of material and protrusion profile embossing feature configured to emboss a corresponding protrusion in the sheet of material.

In a further preferred embodiment, the sheet of material comprises any material from a list comprising paper, a cellulose-based material, wool, plant- or animal-based fibrous material.

In a further preferred embodiment, the profile embossing features are further configured to produce a height of the aerodynamic profile that is in a range of 1 to 15 times of a thickness of the sheet of material.

In a further preferred embodiment, the embossing of the sheet of material is configured to be a wallpaper-like embossing producing an uninterrupted and repeating pattern of embossed aerodynamic features and longitudinal delimitation embossed features.

In a further preferred embodiment, one alternance of 2 successive enclosure opening constriction sections has a length equal or smaller than 40 mm.

In a further preferred embodiment, the one alternance of 2 successive constriction sections is preferably between 3 mm and 30 mm.

In a further preferred embodiment, each one of the plurality of profile embossing features are either one of a protrusion and a recess feature, whereby heights, in case of protrusion features, or depths in case of recess features, are in a range between 0,1 mm and 2,5 mm.

In a further preferred embodiment, the sheet of material has a grammage in a range between 10 gsm and 100 gsm and a thickness in a range between 0,02 mm and 1,5 mm.

In a further aspect the invention provides an embossing set-up for manufacturing an embossed sheet of material configured to be folded and obtain a filtering element configured for an inhalable drug delivery device, and for filtering a mainstream gas flow passing through the filtering element, The set-up comprises features of a patrix-matrix roller embossing system configured to emboss the sheet of material with a plurality of stripes, in a nip between the patrix-matrix embossing rollers, each stripe comprising corresponding embossing features on each of a patrix embossing roller and a matrix embossing roller of the embossing rollers system, and each embossed stripe being oriented longitudinally on the sheet of material with respect to a feed direction of the sheet of material fed to the nip. The embossing features comprise profile embossing features configured for embossing at least an aerodynamic profile on the sheet of material, the profile embossing features being arranged according to a radial direction of the stripe on the embossing rollers, the embossed aerodynamic profile being configured to modify in a determined manner flow properties for the mainstream gas flow passing through the filter element by creating a gas flow turbulence occurrence in the filtering element. The embossing features further comprises radial embossing features configured to delimitate each stripe on opposite radial sides of the stripe, on the patrix-matrix embossing rollers, and further configured to form longitudinal delimitation embossed features that delimitate the embossed stripe on the sheet of material, on opposite longitudinal sides of the embossed stripe, wherein the radial embossing features are further configured to form a plurality of enclosing walls on the patrix-matrix embossing rollers describing at least an enclosure around one or a plurality of the profile embossing features, and, for each enclosure, an enclosure opening in the enclosure connecting the enclosure to a successive enclosure in radial direction of the stripe, the enclosure having a corresponding maximum enclosure expansion section area in axial direction of the stripe and the enclosure opening having a corresponding enclosure opening constriction section area in the axial direction of the stripe which is smaller than the corresponding maximum enclosure expansion section area; and to define at least one alternance of the enclosure opening constriction section area and the maximum enclosure expansion section area in the longitudinal direction of the stripe, formed by the enclosure opening and the enclosure respectively, with a cross-section area ratio between the maximum enclosure expansion section area and the enclosure opening constriction section area of the profile in a range from 8:1 to 2:1.

In a further preferred embodiment, the radial embossing features are further configured to emboss a folding line into the sheet of material.

In a further preferred embodiment, a first set of the profile embossing features in a first one of the stripes is designed for a determined gas flow turbulence in a first longitudinal direction of a corresponding embossed first one of the stripes, and a second set of the profile embossing features in a second one of the stripes adjacent to the first one is designed for the determined gas flow turbulence in a second longitudinal direction of a corresponding embossed second one of the stripes, opposite to the first longitudinal direction.

In a further preferred embodiment, the profile embossing features comprise at least one from a list comprising a recess profile embossing feature configured to emboss a corresponding recessed shape in the sheet of material and a protrusion profile embossing feature configured to emboss a corresponding protrusion in the sheet of material.

In a further preferred embodiment, the sheet of material comprises any material from a list comprising paper, a cellulose-based material, wool, plant- or animal-based fibrous material.

In a further preferred embodiment, the profile embossing features are further configured to produce a height of the aerodynamic profile that is in a range of 1 to 15 times of a thickness of the sheet of material.

In a further preferred embodiment, the patirx-matrix rollers and the embossing features are configured for embossing of the sheet of material to be a wallpaper-like embossing producing an uninterrupted and repeating pattern of embossed aerodynamic features and longitudinal delimitation embossed features.

Brief description of the figures

The invention will be better understood through the detailed description of preferred embodiments and in reference to the figures, wherein

Figure 1 illustrates an embossing set-up for manufacturing an embossed sheet of material configured to be folded and obtain a filtering element according to an example embodiment of the invention;

Figure 2 illustrates an embossing set-up according to a further example embodiment of the invention;

Figure 3 schematically illustrates a top view of an embossed sheet of material issued from the method of manufacturing according to a further example embodiment of the invention;

Figure 4 illustrates a schematic section of congruent patirx-matrix rollers with embossing features according to a further example embodiment of the invention;

Figure 5 schematically illustrates a top view of an embossed sheet of material issued from the method of manufacturing according to a further example embodiment of the invention;

Figures 6a and 6b schematically illustrate surface zones from a patirx embossing roller and a matrix embossing roller configured to be used in embossing a sheet of material according to a further example embodiment of the invention;

Figure 7 schematically illustrates a top view of an embossed enclosure and embossed profile features with effects that they produce on a mainstream smoke passing through the embossed enclosure according to a further example embodiment of the invention;

Figures 8a and 8b schematically illustrate surface zones from a matrix embossing roller and a matrix embossing roller configured to be used in embossing a sheet of material according to a further example embodiment of the invention;

Figure 9 schematically illustrates a top view of two consecutive embossed enclosures and embossed profile features with effects that they produce on a gas passing through the embossed enclosures according to a further example embodiment of the invention;

Figure 10 schematically illustrates a top view of two consecutive embossed enclosures and embossed profile features with effects that they produce on a gas passing through the embossed enclosures according to a further example embodiment of the invention;

Figure 11 schematically illustrates a sheet of material embossed with profile embossing features and radial embossing features in a wall-paper like manner with a suggested way of cutting stripes to obtain a filtering element, according to a further example embodiment of the invention;

Figure 12 schematically illustrates a sheet of material embossed with profile embossing features and radial embossing features in a wall-paper like manner with a suggested way of cutting stripes to obtain a filtering element, according to a further example embodiment of the invention;

Figure 13 schematically illustrates how a filtering element, in this case a cigarette filter may be mounted to a tobacco containing section in order to obtain a cigarette according to prior art;

Figure 14 schematically illustrates how a filtering element and an inhalable drug containing part of an inhalable drug delivery system may be mounted according to prior art;

Figure 15 contains a flowchart illustrating an example embodiment of a method for manufacturing an embossed sheet of material according to the invention;

Figure 16 is a picture of an embossed sheet of material obtained with the invention according to an example embodiment;

Figure 17 is a further picture of an embossed sheet of material obtained with the invention according to an example embodiment; and

Figure 18 contains a flowchart illustrating a further example embodiment of a method for manufacturing an embossed sheet of material according to the invention.

Same references are used to reference same or similar feature illustrated throughout the figures.

Detailed description of preferred embodiments

As previously mentioned, the invention is in the field of manufacturing for the inhalable drug delivery system industry, including smoking products in which medical drugs or nicotine may be dispensed in a gas to a user in various inhalable ways, comprising for example vapor, heated tobacco, and conventional burned tobacco as known from cigarettes and cigars, more specifically in a field of embossing, and relating to a component of a filtering element. Accordingly, the filtering element be configured to filter the gas, i.e., a mainstream gas flow. In one example, the filtering element may correspond to a cigarette filter used in a tobacco cigarette and the mainstream gasflow produced to be filtered is from smoke of burned tobacco. In a further example, the filter element may correspond to a non-burning cigarette filter used in a non-burning tobacco cigarette, in which case the mainstream gas flow produced to be filtered results from heating the tobacco. Various other embodiments, in which for example nicotine would be included in some other gas, for example vapour, the filter element would be configured to filter the corresponding mainstream gas flow and possibly retain particles that need not be included in the inhaled filtered gas administrated to a user.

The inventive device and method result from ecology-motivated research which for example aims to replace conventional cellulose acetate cigarette filters with other categories of suitable sheet-materials, , more preferably with filters made of paper-based materials, or any material from a list comprising paper, wool, plant- or animal-based fibrous material.

The invention provides a method and a device configured for manufacturing a sheet of material that may be used as a component of a filtering element and that comprises embossed features for influencing a flow of the mainstream gas flow traversing the filtering element. The embossed features have a direct impact on slowing / speeding of the mainstream gas flow and, in that manner, reducing or enhancing the retention of particulates from the gas in fibers of the sheet of material.

Preferably the sheet of material is a cellulose-based material, or any material from a list comprising paper, wool, plant- or animal-based fibrous material.

Referring to **Figure 1** this illustrates an embossing set-up **100** according to an example embodiment of the invention. The embossing set-up **100** is configured for manufacturing an embossed sheet of

material **200**, which in turn is configured to be folded and obtain a filtering element configured for filtering a mainstream gas flow passing through the filtering element (filtering element and mainstream gas flow not illustrated in **Figure 1**). Without further tools attached to it, the embossing set-up **100** may also be denoted as an offline embossing system. The embossing set-up **100** comprises matrix-matrix embossing rollers, i.e., a first embossing roller **101** and a second embossing roller **102**, and is configured to realize matrix-matrix embossing on the sheet of material **103**. The first embossing roller **101** and the second embossing roller **102** may optionally be mounted in a quick exchange device **104** and are configured to cooperate with each other to emboss in a nip **105** the sheet of material **103** fed between the first embossing roller **101** and the second embossing roller **102**. A synchronization of the first embossing roller **101** and the second embossing roller may be implemented in various manners, one of which is suggested in the illustration of **Figure 1**, and is not limitative for the embossing set-up **100**, which comprises toothed wheels on the extremities of the rollers, which cooperate with each other. Other embodiments for synchronization may for example involve a servo-control mechanism (not illustrated) which controls angular positions of each roller relative to the other roller, or a combination of toothed wheels and the servo-control mechanism.

As a result of the embossing, the embossed sheet of material **200** is obtained with a plurality of embossed features (not individually shown in **Figure 1**, and represented as a grid on the surface of the embossed sheet of material **200** for a better reading). For further explanations, a zone **209**, which will subsequently be examined in the description, e.g., in relation to examples illustrated in **Figure 3**, is identified on the embossed sheet of material **200**.

An optional bobbin dispensing device (not illustrated) may be configured to carry a bobbin with a web of sheet of material **103** and unwind it out towards the embossing set-up **100**. A product bobbin device (not illustrated) may also optionally be provided to rewind the web of embossed sheet of material **200** for later use in a filtering element manufacturing.

The sheet of material **103** may for example be provided in the form of a web of sheet material, which may for example comprise cellulose-based material, or any material from a list comprising paper, wool, plant- or animal-based fibrous material.

Further concerning the sheet of material **103**, this preferably comprises fibers with a cut length in a first range of 0,5 mm to 6,0 mm, and with a diameter in a second range of 10 μm to 500 μm , the fibers being randomly distributed to deliver an air permeability. The sheet of material's air permeability is configured with filtration capabilities of substances present in a gas, e.g., cigarette or any other gas as mentioned for example in the previously presented gases.

A further preferred embodiment of the embossing set-up **100** according to the invention may be part of an online production process as illustrated in **Figure 2**, the embossing set-up **100** then being part of an online production line for manufacturing a filter element **208** of length **L**. The online production line further comprises for example a compacting device **201** comprising a funnel **202** into which the

embossed sheet of material **200** is fed, folded and formed into a filter rod **203** output by the compacting device **201**. Hence the embossed sheet of material **200** is compacted with the funnel **202**. The filter rod **203** may be pulled by means of a pulling jig **204** to a further process step of cutting illustrated in magnified part **205** of **Figure 2**. The further process step involves cutting the filter rod **203** into individual pieces comprising, as an example, two filter elements **208** each, having the length **L**, by means of a cutting device **206**. As previously described in **Figure 1** as being an option, the production line may comprise the bobbin dispensing device **207** configured to carry the bobbin with the web of sheet of material **103** and unwind it out towards the embossing set-up **100**.

In the following, and referring to **Figures 3** and **5**, some products of embossed sheet material resulting from the inventive method are presented.

Further down, in **Figures 6a–6b** and **Figures 8a–8b**, some examples of embossing features to be used in the inventive embossing set-up of method are presented.

Figure 3 shows a top view **300** from the zone **209** out of **Figure 1**, of the embossed sheet of material **200** (reference **200** not used in **Figure 3**) embossed according to an example embodiment of the invention, in which the embossed zones are depicted by a plurality of embossed features, comprising an embossed aerodynamic profile with embossed first profile features **301a**, **301b** and embossed second features **302a**, **302b**. The embossed features further comprise longitudinal delimitation embossed features **310**, two adjacent ones of which that delimitate a first stripe **311**, or a second stripe **312**. Furthermore, for a better understanding, a cross-section along a line **303** is depicted in a magnified view **304**, to evidence a height profile **305** of the embossed sheet of material **200** with a thickness **d**, revealing a cross-section through embossed second features **302a**, **302b** and longitudinal delimitation embossed features **310**, which present heights **h₂** and **h₁** respectively. In preferred embodiments, **h₁ ≥ h₂**, whereas the height **h₁** (which can be also considered as a thickness increase of the sheet of material after embossing) is chosen to be particularly in a range **15d ≥ h₁ ≥ 2d**.

The first profile features **301a** and **301b** form a plurality of first elements of the embossed aerodynamic profile, which are aligned in the first stripes **311** having a direction parallel to a feed direction **307** of the embossed sheet of material **200**, i.e., a direction according to which the sheet of material **103** was fed in the nip **105** of the patirx-matrix embossing rollers **101**, **103** to obtain the embossed sheet of material **200** fed out of the nip **105** as shown in **Figure 1**. The first elements respectively form a minimum constriction section area **308** and a maximum expansion section area **309** in a radial direction perpendicular to the feed direction. The latter 2 areas designate a surface oriented perpendicular to a radial direction and representative of the cross-section area at the minimum constriction section and the maximum expansion section respectively. The feature of area will continue to be used in this manner throughout the text hereunder unless otherwise explained.

The second profile features **302a** and **302b** form a plurality of second elements of the embossed aerodynamic profile, which are aligned in the second stripes **312** having the direction parallel to the feed direction **307**. The second elements respectively form the minimum constriction section and the maximum expansion section in the radial direction, and are inverted in feed directions as compared to the minimum constriction section **308** and the maximum expansion section **309** of the first elements. This is configured to cope with an air flow of mainstream gas flow in an inhalable drug delivery device that may occur from each one of directions indicated with arrows **306** when the embossed sheet of material **200** is transformed into a filtering element (not illustrated in **Figure 3**).

The first and second elements of the embossed aerodynamic profile are equally spaced from each other on lines in radial direction with a period ℓ , as are longitudinal delimitation embossed features **310**. The first elements of the embossed aerodynamic profile are also equally spaced from one to another in lines oriented parallel to the feed direction **307** with a pitch p . Similarly, the second elements of the embossed aerodynamic profile are also equally spaced from one to another in lines oriented parallel to the feed direction **307** with the pitch p .

Considering a direction **306** of a mainstream gas flow, the embossed first profile features **301a** and **301b** and second profile features **302a** and **302b** are configured in such a manner that the mainstream gas flow flowing that passes them experiences a variation of an available aperture. This modifies a local gas flow velocity at the first and second profile features, and induces a specific behavior (detailed at a later point in this description) of the mainstream smoke, possibly increasing the mainstream smoke's residence time in the filter element (not illustrated in **Figure 3**). Through embossing trials and related pressure drop measurements, a preferred ratio of roughly 8:1 to 2:1 for the restriction of the available aperture was found.

Figure 4 illustrates schematically the obtaining of the embossed first and second features **301a**, **301b**, **302a**, **302b** and the longitudinal delimitation embossed features **310** according to the invention, in its principle without actually showing these features in the Figure. **Figure 4** depicts details from two substantially congruent matrix-matrix rollers **401** and **402**, whereas the roller **401** contains protuberances **413** and the roller **402** exhibits corresponding depressions **404**, accommodating a nip **405** for the sheet of material to be embossed (not represented here). For purpose of simplicity, **Figure 4** represents the particular case in which embossed features would present each a same height, and this should not be understood as a limitation.

Figure 5 shows a further top view **500** from the zone **209** out of **Figure 1**, of the embossed sheet of material **200** embossed according to a further example embodiment of the invention, in which the embossed zones are depicted by a plurality of embossed features, comprising an embossed aerodynamic profile with embossed third profile features **501a**, **501b** and embossed fourth profile features **502a**, **502b**, the third embossed profile features and the fourth embossed profile features forming respectively a third element and a fourth element, each element in turn defining a small

aperture and a large aperture. The plurality of embossed profile features further comprises embossed baffle features **512** which are placed in regions of large aperture of the third elements and the fourth elements, hence locally obturating a maximum of 50%, preferably 30%, of the large aperture. The embossed features further comprise longitudinal delimitation embossed features **510**, two adjacent ones of which that delimitate a first stripe **511**, or a second stripe **512**. Furthermore, for a better understanding, a cross-section along a line **503** is depicted in a magnified view **504**, to evidence a height profile **505** of the embossed sheet of material **200** with a thickness **d**, revealing a cross-section through embossed fourth features **502a**, **502b**, longitudinal delimitation embossed features **510**, and an embossed first baffle feature **513**, which present heights **h₂**, **h₁** and **h₃** respectively. In preferred embodiments, $h_1 \geq h_2 \geq h_3$, whereas the height **h₁** (which can be also considered as the thickness increase of the sheet of material after embossing) is chosen to be particularly in a range $15d \geq h_1 \geq 2d$. In further embodiments, **h₂** is chosen to be close to **h₁**, for example $h_2 \geq 0.8 h_1$. Furthermore, in preferred embodiments and as shown in the view **509**, the first embossed baffle structures **513** may also lie embossed in an opposite direction, with respect to an embossing direction of features **501a**, **501b**, **502a**, and **502b**.

In case the filtering element is used in a cigarette for filtering cigarette smoke, and more particularly for "low tar" cigarettes, in which a higher smoke (gas) residence time in the filtering element (i.e., a higher particulate retention) is to be obtained, the embossing design may comprise the baffles, to further enhance the smoke (gas) flow turbulence occurring in the maximum expansion section area that follows after a minimum constriction section area. The baffles may be embossed either (i) in the same direction as the expansion-constriction walls, i.e., obstacle turbulence, or (ii) in the opposite direction as the expansion / constriction walls, i.e., expansion turbulence.

The plurality of third elements of the embossed aerodynamic profile, are aligned in the first stripes **511** having the direction parallel to the feed direction **307** of the embossed sheet of material **200**, i.e., a direction according to which the sheet of material **103** was fed in the nip **105** of the matrix-matrix embossing rollers **101**, **103** to obtain the embossed sheet of material **200** fed out of the nip **105** as shown in **Figure 1**. The third elements respectively form a minimum constriction section **508** and a maximum expansion section **509** in a radial direction perpendicular to the feed direction **307**, the maximum expansion section **509** being located on the side of the large aperture.

The plurality of fourth elements of the embossed aerodynamic profile, are aligned in the second stripes **512** having the direction parallel to the feed direction **307**. The fourth elements respectively form the minimum constriction section and the maximum expansion section in the radial direction, but inverted in feed direction as compared to the minimum constriction section **508** and the maximum expansion section **509** of the third elements. This is configured to cope with an air flow of mainstream gas flow in an inhalable drug delivery device that may occur from each one of directions indicated with arrows **506** when the embossed sheet of material **200** is transformed into a filtering element (not illustrated in **Figure 5**).

The third and fourth elements of the embossed aerodynamic profile are equally spaced from each other on lines in radial direction with a period ℓ , as are longitudinal delimitation embossed features **510**. The third elements of the embossed aerodynamic profile are also equally spaced from one to another in lines oriented parallel to the feed direction **307** with a pitch p . Similarly, the fourth elements of the embossed aerodynamic profile are also equally spaced from one to another in lines oriented parallel to the feed direction **307** with the pitch p .

Considering the direction **506** of the mainstream gas flow, the embossed third profile features **501a** and **501b** and fourth profile features **502a** and **502b** are configured in such a manner that the mainstream gas flow flowing passed them experiences a variation of the available aperture. This modifies a local gas flow velocity and induces a specific behavior (detailed at a later point in this description) of the mainstream gas flow, possibly increasing the mainstream gas flow's residence time in the filtering element (not illustrated in **Figure 5**). Through embossing trials and related pressure drop measurements, a preferred ratio of roughly 15:1 to 2:1 for the restriction of the available aperture was found.

For ease of comprehension, **Figures 3** and **5** are depicting elementary embossed features, to be embossed according to the invention into a sheet of material that is used to make a filter rod and subsequently a filtering element. The following **Figures** will depict further, more complex examples of embodiments of the invention, found in iterative ameliorations of the ensemble of

- (i) mechanical behavior of the material during the process of embossing, and
- (ii) filtration properties (e.g., pressure drop for a given stripe width, or material-quantity reduction for a given pressure drop to be obtained).

These iterative ameliorations show the advantages of embossing structures with rounded edges and shapes in order to obtain the series of constriction and expansion sections for the gas flow, according to the invention.

Illustrating a preferred embodiment, **Figures 6a** and **6b** present example surface zones from a first (patrix) — reference **101** in **Figure 1** — and a second (matrix) — reference **102** in **Figure 1** — embossing rollers used to emboss a sheet of material and optionally obtain a filter rod and subsequently fabricate a filtering element. An isometric view from a surface zone **601** of the first (patrix) embossing roller **101** (not represented) is shown in **Figure 6a**, which also includes a top view **603** from a segment of the surface zone **601** surrounded with dashed lines. **Figure 6b** contains an isometric view from a surface zone **602** of the second (matrix) roller **102** (not represented), as well as a top view **604** from a segment of the surface zone **602**. Surfaces referenced **605** and **609** are respectively considered as reference levels for the surface zones **601** and **602**, to which the heights in **Figure 6a** and the depths in **Figure 6b** of the embossing features engraved into the rollers, which will eventually be embossed into the sheet of material, are referred to. The surface zone **601** contains

protrusions **606**, corresponding to recesses **610** of the surface zone **602**. The protrusions **606** / recesses **610** correspond to embossing features that comprise profile embossing features **607** / **611** configured for embossing at least an aerodynamic profile in a plurality of stripes oriented in radial direction **613**, and radial embossing features **605** / **609** configured to delimitate each stripe on opposite radial sides of the stripe. The top view **603** for example illustrates a part of two stripes **614**. The radial embossing features **605** / **609** further form a plurality of enclosing walls **615** that describe enclosures around a plurality of the profile embossing features **607** and form an enclosure opening **608** in each enclosure in radial direction of the stripe. Hence two consecutive structures enclosures of enclosing walls **615** (or **616**) are connected through the enclosure opening **608** (or **612**), which may also be called a enclosure opening constriction section **608** (enclosure opening constriction section **612** on the opposite roller) of smallest aperture. A large aperture in radial direction formed at the largest aperture in radial direction of an enclosure is also called maximum enclosure expansion section. Additional maximum expansion and minimum constriction sections for a mainstream gas flow (through the filtering element to be created) (mainstream gas flow not illustrated) are created into the embossed sheet of material by means of the profile embossing features, i.e., by means of the protrusions **607** and the corresponding recesses **611**.

Figure 7 schematically illustrates a top view of an embossed enclosure and embossed profile features together with lines indicating effects that they produce on a mainstream gas flow **701** passing through the embossed enclosure according to a further example embodiment of the invention. **Figure 7** shows effects of embossing features after they have been embossed in a sheet of material **200** (reference **200** not used in **Figure 7**). More specifically, **Figure 7** illustrates a plurality of embossed enclosing walls **705** that describe an enclosure around a plurality of profile embossed features **707**. The resulting embossed sheet of material is used to filter the mainstream gas flow **701** in a filtering element (filtering element not illustrated as a whole in **Figure 7**). The effects of embossed features on the mainstream gas flow **701** are illustrated by flow lines **702**. As is generally known, gas from an inhalable drug delivery device, e.g., cigarette smoke may contain gas particulates **703** which are shown schematically using black dots. According to fluid dynamics, if there is an expansion **711** after a constriction **712**, **708**, in the main gas flow **701**, turbulences **704**, **706** occur. Gas particulates **703** are engaged in the turbulences **704**, **706**, whereas a part of them are therefore brought in the vicinity of the embossed walls of the expansion – constriction features **712**, **708** – and embossed profile features **707**, as may be seen in magnification view **713** of a side of an embossed profile feature **707**, in which fibrous structure **710** of the sheet of material **900** retains gas particulates **703**. **p** is the distance between two successive constriction sections.

Illustrating a further preferred embodiment, **Figures 8a** and **8b** present example surface zones from a first (patrix) — reference **101** in **Figure 1** — and a second (matrix) — reference **102** in **Figure 1** — embossing rollers used to emboss a sheet of material and optionally obtain a filter rod and subsequently fabricate a filtering element. An isometric view from a surface zone **801** of the first (patrix) embossing roller **101** (not represented) is shown in **Figure 8a**, which also includes a top view

803 from a segment of the surface zone **801** surrounded with dashed lines. **Figure 8b** contains an isometric view from a surface zone **802** of the second (matrix) roller **102** (not represented), as well as a top view **804** from a segment of the surface zone **802**. Surfaces referenced **805** and **810** are respectively considered as reference levels for the surface zones **801** and **802**, to which the heights in **Figure 8a** and the depths in **Figure 8b** of the embossing features engraved into the rollers, which will eventually be embossed into the sheet of material, are referred to. The surface zone **801** contains protrusions **806**, corresponding to recesses **811** of the surface zone **802**. The protrusions **806** / recesses **811** correspond to embossing features that comprise profile embossing features **807** / **812**, **808** / **813** configured for embossing at least an aerodynamic profile in a plurality of stripes oriented in radial direction **613**, and radial embossing features **806** / **811** configured to delimitate each stripe on opposite radial sides of the stripe. The top view **803** for example illustrates a part of two stripes **815**. The radial embossing features **806** / **811** further form a plurality of enclosing walls **816** that describe enclosures around at least one profile embossing features **807** per enclosure, and form an enclosure opening **809** / **814** in each enclosure in radial direction of the stripe. Hence two consecutive structures enclosures of enclosing walls **816** are connected through the enclosure opening **809**, which may also be called an enclosure constriction section **809** of smallest aperture. A large aperture in radial direction formed at the largest opening in radial direction of an enclosure is also called maximum enclosure expansion section. Additional expansion and constriction sections for a smoke flow (through the filter to be created) (smoke flow not illustrated) are created into the embossed sheet of material by the profile embossing features by means of the protrusions **807** and the corresponding recesses **812**.

Figure 9 schematically illustrates a top view of two embossed enclosures and two embossed profile features with effects that they produce on a mainstream gas flow **901** passing through the embossed enclosures according to a further example embodiment of the invention. **Figure 9** shows effects of embossing features after they have been embossed in a sheet of material. More specifically, **Figure 9** illustrates a plurality of embossed enclosing walls **905** that describe successive enclosures around a plurality of profile embossed features **907**, i.e., one profile embossed feature per enclosure in this example. The resulting embossed sheet of material is used to filter the mainstream gas flow **901** in a filtering element (filtering element not illustrated as a whole in **Figure 9**). The effects of embossed features on the mainstream gas flow **901** are illustrated by flow lines **902**. As is generally known, gas from an inhalable drug delivery device, e.g., cigarette smoke may contain gas particulates **903** which are shown schematically using black dots. According to fluid dynamics, if there is an expansion **911** after a constriction **910**, in the mainstream gas flow **901**, turbulences **904**, **906** occur. Gas particulates **903** are engaged in the turbulences **904**, **906**, whereas a part of them are therefore brought in the vicinity of the embossed walls of the enclosure expansion – enclosure constriction features **910** – and embossed profile features **907**, as may be seen in magnification view **912** of a side of an embossed profile feature **907**, in which fibrous structure **913** of the sheet of material retains gas particulates **909** (as opposed to non-retained gas particulates **903**). **p** is the distance between two successive enclosure constriction sections.

Figure 10 schematically illustrates a top view of two embossed enclosures and embossed profile features with effects that they produce on a mainstream gas flow **1001** passing through the embossed enclosures according to a further example embodiment of the invention. **Figure 10** shows effects of embossing features after they have been embossed in a sheet of material. More specifically, **Figure 10** illustrates a plurality of embossed enclosing walls **1006** similar as those in **Figure 9** that describe successive enclosures around a plurality of profile embossed features **1003** and **1005**, i.e., one profile embossed feature per enclosure in this example, separated by enclosure constrictions **1007**. The resulting embossed sheet of material is used to filter the mainstream gas flow **1001** in a filtering element (filtering not illustrated as a whole in **Figure 10**). The effects of embossed features on the mainstream gas flow **1001** are illustrated by flow lines **1008**. Magnified views **1002** and **1004** give a closer insight on successive expansion zones comprising embossed profile features **1003** and **1005** respectively. In case of the expansion zone comprising embossed profile feature **1003**, a volume of the expansion zone is further increased with a recessed shape of the embossed profile feature **1003**, which locally modifies the gas flow and induces a supplementary turbulence. In the case of the expansion zone comprising the embossed profile feature **1005**, a protrusion shape of the embossed feature **1005** diminishes the volume of the expansion zone embossed into the sheet of material, generating a supplementary transition constriction – expansion, which will induce local turbulences and increase the gas residence time in the filter, in contact with the material of the embossed sheet, increasing therefore a retention efficiency. p is the distance between two successive enclosure constriction sections.

According to the invention, and considering the subsequent possible manufacturing steps to produce the filtering elements, there is no correlation between a particular feature of the design embossed into the sheet of material and the exact material range, from which a filtering element is produced, as illustrated in **Figure 11**. **Figure 11** shows a sheet of material **200** embossed according to the invention and bearing alternating paths of periodical maximum enclosure expansion – enclosure constriction sections, whereas p (not illustrated) is the distance between two successive enclosure constriction sections. From this sheet of material **200**, filtering elements **1101** of length L are produced. For illustration, four arbitrary cutting stripes **1102 1111** are indicated, where the embossed sheet of material may be cut to obtain the filtering elements **1101**. The invention requires no correlation between the stripes **1102** and a position of the enclosure constriction (or enclosure expansion) sections, due to the fact that the distance p (not illustrated) between two consecutive enclosure constriction sections is chosen in correlation to the final length L of the filtering element, namely $p < L$, preferably $p \leq \frac{1}{4}L$. Typical values for p may lie in a range between 3 mm and 30 mm. This is an advantage also known as wall-paper like type of embossing.

Figure 12 also shows a sheet of material **200** embossed according to the invention and bearing alternating paths of periodical maximum enclosure expansion – enclosure constriction sections, whereas p' (not illustrated) is the distance between two successive enclosure constriction sections.

From this sheet of material, filtering elements **1201** of length **L** are produced. As previously in **Figure 11**, four arbitrary cutting stripes **1202** are indicated, where the embossed sheet of material may be cut to obtain the filtering elements **1201**. As explained above, the invention requires no correlation between the cutting stripes **1202** and a position of the enclosure constriction (or enclosure expansion) sections, due to the fact that the distance **p'** (not illustrated) between two consecutive enclosure constriction sections is chosen in correlation to the final length **L'** of the filtering element, namely $p' < L'$, preferably $p' \leq \frac{3}{4}L'$. This is an advantage also known as wall-paper like type of embossing.

Figure 13 schematically illustrates how a cigarette filter **1301** -type filtering element from a double filter **208** may be mounted to a tobacco containing section **1303** in order to obtain a cigarette **1305** according to prior art. Part **(A)** shows the double filter **208**. Part **(B)** shows the double filter **208** positioned between tobacco containing sections **1303**, and a filter paper **1302** being wound and glued around the double filter **208** and partly over a part of each tobacco containing section **1303**, resulting in a double cigarette **1304** shown in part **(C)**. Part **(D)** shows one of cigarettes **1305** obtained after cutting a double cigarette **1304** in a middle **1306** thereof.

Figure 14 schematically illustrates the structure of an inhalable drug delivery system **1400A** and **1400B**, according to the prior art. Part **(A)** depicts a delivery system comprising a drug containing component **1401** and a filtering element **1402** fabricated using a sheet of material embossed according to the invention. Part **(B)** depicts an inhalable drug delivery system comprising the drug containing component **1401**, a cooling component **1403**, and of the filtering element **1402** fabricated using a sheet of material embossed according to the invention.

Figure 15 contains a flowchart illustrating an example embodiment of a method for manufacturing an embossed sheet of material **1506** according to an example embodiment of the invention, configured to be folded and obtain a filtering element for filtering a mainstream gas flow passing through the filtering element. The method comprises a step of providing **1500** the sheet of material **1501**. The method further comprise a step of embossing **1502** the sheet of material **1501** with a plurality of stripes **1505**, by means of a patirx-matrix embossing roller system, and by feeding the sheet of material **1501** to a nip between the patirx-matrix embossing rollers, each stripe **1505** comprising corresponding embossing features on each of a patirx embossing roller and a matrix embossing roller, and each embossed stripe being oriented longitudinally with respect to a feed direction of the sheet of material fed to the nip. The embossing features comprise profile embossing features **1503** configured for embossing at least an aerodynamic profile on the sheet of material, the profile embossing features **1503** being arranged according to a radial direction of the stripe **1505** on the embossing rollers, the embossed aerodynamic profile being configured to modify in a determined manner flow properties for the mainstream gas flow passing through the filtering element by creating a gas flow turbulence occurrence in the filtering element. The profile embossing features **1503** in the stripe **1505** form at least an alternance of a minimum constriction section area and a maximum expansion section area in the radial direction of the stripe on the embossing roller, with a cross-section area ratio between the

maximum expansion section area and the minimum constriction section area in a range from 15:1 to 2:1. The embossing features further comprise radial embossing features **1504** configured to delimitate each stripe **1505** on opposite radial sides of the stripe **1505**, on the patrix-matrix embossing rollers, and further configured to form longitudinal delimitation embossed features that delimitate the embossed stripe on the embossed sheet of material **1506**, on opposites sides of the embossed stripe.

Preferably, in a further example embodiment of the method for manufacturing according to the invention, the radial embossing features **1504** are further configured to form a plurality of enclosing walls on the patrix-matrix embossing rollers describing at least an enclosure around one or a plurality of the profile embossing features, and an enclosure opening in the enclosure connecting the enclosure to a successive enclosure in radial direction of the stripe **1505**, the enclosure having a corresponding maximum enclosure expansion section area in axial direction of the stripe and the enclosure opening having a corresponding enclosure opening constriction section area in the axial direction of the stripe **1505** which is smaller than the corresponding maximum enclosure expansion section. The radial embossing features **1504** are further configured to define at least an alternance of the enclosure opening constriction section and the enclosure expansion section in the longitudinal direction of the stripe **1505**, formed by the opening and the enclosure respectively, with a cross-section area ratio between the maximum enclosure expansion section area and the enclosure opening constriction section in a range from 15:1 to 2:1.

Figure 18 contains a flowchart illustrating an example embodiment of a method for manufacturing an embossed sheet of material **1806** according to an example embodiment of the invention, configured to be folded and obtain a filtering element for filtering a mainstream gas flow passing through the filtering element. The method comprises a step of providing **1800** the sheet of material **1801**. The method further comprise a step of embossing **1802** the sheet of material **1501** with a plurality of stripes **1805**, by means of a patrix-matrix embossing roller system, and by feeding the sheet of material **1801** to a nip between the patrix-matrix embossing rollers, each stripe **1805** comprising corresponding embossing features on each of a patrix embossing roller and a matrix embossing roller, and each embossed stripe being oriented longitudinally with respect to a feed direction of the sheet of material fed to the nip. The embossing features comprise profile embossing features **1803** configured for embossing at least an aerodynamic profile on the sheet of material, the profile embossing features **1803** being arranged according to a radial direction of the stripe **1805** on the embossing rollers, the embossed aerodynamic profile being configured to modify in a determined manner flow properties for the mainstream gas flow passing through the filtering element by creating a gas flow turbulence occurrence in the filtering element. The embossing features further comprise radial embossing features **1804** configured to delimitate each stripe **1805** on opposite radial sides of the stripe **1805**, on the patrix-matrix embossing rollers, and further configured to form longitudinal delimitation embossed features that delimitate the embossed stripe on the embossed sheet of material **1806**, on opposites sides of the embossed stripe. The radial embossing features **1804** are further configured to form a plurality of enclosing walls on the patrix-matrix embossing rollers describing at least an enclosure

around one or a plurality of the profile embossing features, and an enclosure opening in the enclosure connecting the enclosure to a successive enclosure in radial direction of the stripe **1805**, the enclosure having a corresponding maximum enclosure expansion section area in axial direction of the stripe and the enclosure opening having a corresponding enclosure opening constriction section area in the axial direction of the stripe **1805** which is smaller than the corresponding maximum enclosure expansion section. The radial embossing features **1804** are further configured to define at least an alternance of the enclosure opening constriction section and the enclosure expansion section in the longitudinal direction of the stripe **1805**, formed by the opening and the enclosure respectively, with a cross-section area ratio between the maximum enclosure expansion section area and the enclosure opening constriction section in a range from 15:1 to 2:1.

Figure 16 contains a photograph of an embossed sheet of material, embossed according to the invention, in which the reference surface **805**, the protrusions **806** (i.e., radial embossing features), the opening **809**, and profile embossing features **808** are illustrated.

Figure 17 contains a photograph of an embossed sheet of material, embossed according to the invention, in which the reference surface **605**, the protrusions **606**, the profile embossing features **607**, and the opening **608**, which may also be called a constriction section, are illustrated.

Claims

1. A method for manufacturing an embossed sheet of material configured to be folded and obtain a filtering element configured for an inhalable drug delivery device, and for filtering a mainstream gas flow passing through the filtering element, comprising steps of:
providing the sheet of material; and
embossing the sheet of material with a plurality of stripes, by means of a patrix-matrix embossing rollers system, and by feeding the sheet of material to a nip between the patrix-matrix embossing rollers, each stripe comprising corresponding embossing features on each of a patrix embossing roller and a matrix embossing roller of the embossing rollers system, and each embossed stripe being oriented longitudinally on the sheet of material with respect to a feed direction of the sheet of material fed to the nip,
the embossing features comprising:
profile embossing features configured for embossing at least an aerodynamic profile on the sheet of material, the profile embossing features being arranged according to a radial direction of the stripe on the embossing rollers, the embossed aerodynamic profile being configured to modify in a determined manner flow properties for the mainstream gas flow passing through the filtering element by creating a gas flow turbulence occurrence in the filtering element,
whereby
the profile embossing features in the stripe form at least an alternance of a minimum constriction section area and a maximum expansion section area in the radial direction of the stripe on the embossing roller, with a cross-section area ratio between the maximum expansion section area and the minimum constriction section area in a range from 15:1 to 2:1; and
the embossing features further comprising:
radial embossing features configured to delimitate each stripe on opposite radial sides of the stripe, on the patrix-matrix embossing rollers, and further configured to form longitudinal delimitation embossed features that delimitate the embossed stripe on the sheet of material, on opposite longitudinal sides of the embossed stripe.
2. The method for manufacturing the embossed sheet of material according to claim 1, wherein the radial embossing features are further configured to emboss a folding line into the sheet of material.
3. The method for manufacturing of claim 1 or 2, further wherein

the radial embossing features are further configured
to form

a plurality of enclosing walls on the patirix-matrix embossing rollers describing
at least an enclosure around one or a plurality of the profile
embossing features,

and, for each enclosure,

an enclosure opening in the enclosure connecting the enclosure to a
successive enclosure in radial direction of the stripe,
the enclosure having a corresponding maximum enclosure expansion
section area in axial direction of the stripe and the enclosure
opening having a corresponding enclosure opening
constriction section area in the axial direction of the stripe
which is smaller than the corresponding maximum enclosure
expansion section area, and

to define at least one alternance of the enclosure opening constriction section area
and the maximum enclosure expansion section area in the longitudinal
direction of the stripe, formed by the enclosure opening and the enclosure
respectively, with a cross-section area ratio between the maximum enclosure
expansion section area and the enclosure opening constriction section area of
the profile in a range from 15:1 to 2:1.

4. The method for manufacturing of any one of claims 1 to 3, wherein a first set of the profile embossing features in a first one of the stripes is designed for a determined gas flow turbulence in a first longitudinal direction of a corresponding embossed first one of the stripes, and a second set of the profile embossing features in a second one of the stripes adjacent to the first one is designed for the determined gas flow turbulence in a second longitudinal direction of a corresponding embossed second one of the stripes, opposite to the first longitudinal direction.
5. The method for manufacturing of any one of claims 1 to 4, wherein the profile embossing features comprise at least one from a list comprising a recess profile embossing feature configured to emboss a corresponding recessed shape in the sheet of material and a protrusion profile embossing feature configured to emboss a corresponding protrusion in the sheet of material.
6. The method for manufacturing of any one of claims 1 to 5, wherein the sheet of material comprises any material from a list comprising paper, a cellulose-based material, wool, plant- or animal-based fibrous material.

7. The method for manufacturing of any one of the claims 1 to 6, whereby the profile embossing features are further configured to produce a height of the aerodynamic profile that is in a range of 1 to 15 times of a thickness of the sheet of material.
8. The method for manufacturing according to any one of the claims 1 to 7, further wherein the embossing of the sheet of material is configured to be a wallpaper-like embossing producing an uninterrupted and repeating pattern of embossed aerodynamic features and longitudinal delimitation embossed features.
9. The method for manufacturing of claim 1, whereby the cross-section area ratio between the maximum expansion section area and the minimum constriction section area is in a range of 8:1 to 3:1.
10. The method for manufacturing according to claim 3, wherein one alternance of two successive enclosure opening constriction sections (p) has a length equal or smaller than 40 mm.
11. The method for manufacturing according to claim 10, wherein the one alternance of two successive enclosure opening constriction sections (p) is preferably between 3 mm and 30 mm.
12. The method for manufacturing according to claim 3, wherein
the profile embossing features further comprise a plurality of baffle (201, 205) embossing features enabling the embossed aerodynamic profile to enhance the gas flow turbulence occurring in at least one of the maximum expansion section areas (107) in an alternance of the maximum expansion section area and the minimum constriction section area,
whereby the plurality of baffle embossing features are embossed successively in longitudinal direction.
13. The method for manufacturing of claim 1, whereby each one of the profile embossing features as a height in a range between 0,1 mm and 2,5 mm.
14. The method for manufacturing of claim 12, whereby each one of the plurality of baffle embossing features are either one of a protrusion and a recess feature, whereby heights in case of protrusion features, or depths in case of recess features are in a range between 0,1 mm and 2 mm.
15. The method for manufacturing according to any one of the preceding claims, wherein the sheet of material has a grammage in a range between 10 gsm and 100 gsm and a thickness in a range between 0,02 mm and 1,5 mm.

16. An embossing set-up for manufacturing an embossed sheet of material configured to be folded and obtain a filtering element configured for an inhalable drug delivery device, and for filtering a mainstream gas flow passing through the filtering element, comprising features of:
a patrix-matrix roller embossing system configured to emboss the sheet of material with a plurality of stripes, in a nip between the patrix-matrix embossing rollers, each stripe comprising corresponding embossing features on each of a patrix embossing roller and a matrix embossing roller of the embossing rollers system, and each embossed stripe being oriented longitudinally on the sheet of material with respect to a feed direction of the sheet of material fed to the nip,
the embossing features comprising:
 profile embossing features configured for embossing at least an aerodynamic profile on the sheet of material, the profile embossing features being arranged according to a radial direction of the stripe on the embossing rollers, the embossed aerodynamic profile being configured to modify in a determined manner flow properties for the mainstream gas flow passing through the filtering element by creating a gas flow turbulence occurrence in the filtering element;
 whereby
 the profile embossing features in the stripe form at least an alternance of a minimum constriction section area and a maximum expansion section area in the radial direction of the stripe on the embossing roller, with a cross-section area ratio between the maximum expansion section area and the minimum constriction section area in a range from 15:1 to 2:1; and
the embossing features further comprising:
 radial embossing features configured to delimitate each stripe on opposite radial sides of the stripe, on the patrix-matrix embossing rollers, and further configured to form longitudinal delimitation embossed features that delimitate the embossed stripe on the sheet of material, on opposite longitudinal sides of the embossed stripe.
17. The embossing set-up of claim 16, wherein the radial embossing features are further configured to emboss a folding line into the sheet of material.
18. The embossing set-up of claim 16, further wherein:
the radial embossing features are further configured
to form

- a plurality of enclosing walls on the matrix embossing rollers describing at least an enclosure around one or a plurality of the profile embossing features,
- and, for each enclosure,
- an enclosure opening in the enclosure connecting the enclosure to a successive enclosure in radial direction of the stripe,
- the enclosure having a corresponding maximum enclosure expansion section area in axial direction of the stripe and the enclosure opening having a corresponding enclosure opening constriction section area in the axial direction of the stripe which is smaller than the corresponding maximum enclosure expansion section area, and
- to define at least one alternance of the enclosure opening constriction section area and the maximum enclosure expansion section area in the longitudinal direction of the stripe, formed by the enclosure opening and the enclosure respectively, with a cross-section area ratio between the maximum enclosure expansion section area and the enclosure opening constriction section area of the profile in a range from 15:1 to 2:1.
19. The embossing set-up of any one of claims 16 to 18, wherein a first set of the profile embossing features in a first one of the stripes is designed for a determined gas flow turbulence in a first longitudinal direction of a corresponding embossed first one of the stripes, and a second set of the profile embossing features in a second one of the stripes adjacent to the first one is designed for the determined gas flow turbulence in a second longitudinal direction of a corresponding embossed second one of the stripes opposite to the first longitudinal direction.
20. The embossing set-up of any one of claims 16 to 18, wherein the profile embossing features comprise at least one from a list comprising a recess profile embossing feature configured to emboss a corresponding recessed shape in the sheet of material and a protrusion profile embossing feature configured to emboss a corresponding protrusion in the sheet of material.
21. The embossing set-up of any one of claims 16 to 20, wherein the sheet of material comprises any material from a list comprising paper, a cellulose-based material, wool, plant- or animal-based fibrous material.
22. The embossing set-up of any one of the claims 16 to 21, whereby the profile embossing features are further configured to produce a height of the aerodynamic profile that is in a range of 1 to 15 times of a thickness of the sheet of material.

23. The embossing set-up of any one of the claims 16 to 22, further wherein the patrix-matrix rollers and the embossing features are configured for embossing of the sheet of material to be a wallpaper-like embossing producing an uninterrupted and repeating pattern of embossed aerodynamic features and longitudinal delimitation embossed features.
24. The embossing set-up of claim 16, whereby the cross-section area ratio between the maximum expansion section area and the minimum constriction section of the profile is in a range of 8:1 to 3:1.
25. A method for manufacturing an embossed sheet of material configured to be folded and obtain a filtering element configured for an inhalable drug delivery device, and for filtering a mainstream gas flow passing through the filtering element, comprising steps of:
providing the sheet of material; and
embossing the sheet of material with a plurality of stripes, by means of a patrix-matrix embossing rollers system, and by feeding the sheet of material to a nip between the patrix-matrix embossing rollers, each stripe comprising corresponding embossing features on each of a patrix embossing roller and a matrix embossing roller of the embossing rollers system, and each embossed stripe being oriented longitudinally on the sheet of material with respect to a feed direction of the sheet of material fed to the nip,
the embossing features comprising:
 profile embossing features configured for embossing at least an aerodynamic profile on the sheet of material, the profile embossing features being arranged according to a radial direction of the stripe on the embossing rollers, the embossed aerodynamic profile being configured to modify in a determined manner flow properties for the mainstream gas flow passing through the filtering element by creating a gas flow turbulence occurrence in the filtering element;
 and
the embossing features further comprising:
 radial embossing features configured to delimitate each stripe on opposite radial sides of the stripe, on the patrix-matrix embossing rollers, and further configured to form longitudinal delimitation embossed features that delimitate the embossed stripe on the sheet of material, on opposite longitudinal sides of the embossed stripe,
wherein:
the radial embossing features are further configured to form

a plurality of enclosing walls on the patrix-matrix embossing rollers
describing at least an enclosure around one or a plurality of
the profile embossing features,
and, for each enclosure,
an enclosure opening in the enclosure connecting the enclosure to a
successive enclosure in radial direction of the stripe,
the enclosure having a corresponding maximum enclosure
expansion section area in axial direction of the stripe
and the enclosure opening having a corresponding
enclosure opening constriction section area in the
axial direction of the stripe which is smaller than the
corresponding maximum enclosure expansion section
area, and

to define at least one alternance of the enclosure opening constriction section
area and the maximum enclosure expansion section area in the
longitudinal direction of the stripe, formed by the enclosure opening
and the enclosure respectively, with a cross-section area ratio
between the maximum enclosure expansion section area and the
enclosure opening constriction section area of the profile in a range
from 15:1 to 2:1.

26. The method for manufacturing the embossed sheet of material according to claim 25, wherein the radial embossing features are further configured to emboss a folding line into the sheet of material.
27. The method for manufacturing of any one of claims 25 to 26, wherein a first set of the profile embossing features in a first one of the stripes is designed for a determined gas flow turbulence in a first longitudinal direction of a corresponding embossed first one of the stripes, and a second set of the profile embossing features in a second one of the stripes adjacent to the first one is designed for the determined gas flow turbulence in a second longitudinal direction of a corresponding embossed second one of the stripes, opposite to the first longitudinal direction.
28. The method for manufacturing of any one of claims 25 to 27, wherein the profile embossing features comprise at least one from a list comprising a recess profile embossing feature configured to emboss a corresponding recessed shape in the sheet of material and a protrusion profile embossing feature configured to emboss a corresponding protrusion in the sheet of material.

29. The method for manufacturing of any one of claims 26 to 28, wherein the sheet of material comprises any material from a list comprising paper, a cellulose-based material, wool, plant- or animal-based fibrous material.
30. The method for manufacturing of any one of the claims 26 to 29, whereby the profile embossing features are further configured to produce a height of the aerodynamic profile that is in a range of 1 to 15 times of a thickness of the sheet of material.
31. The method for manufacturing according to any one of the claims 25 to 30, further wherein the embossing of the sheet of material is configured to be a wallpaper-like embossing producing an uninterrupted and repeating pattern of embossed aerodynamic features and longitudinal delimitation embossed features.
32. The method for manufacturing according to claim 26, wherein one alternance of 2 successive enclosure opening constriction sections has a length equal or smaller than 40 mm.
33. The method for manufacturing according to claim 32, wherein the one alternance of 2 successive constriction sections is preferably between 3 mm and 30 mm.
34. The method for manufacturing of claim 25, whereby each one of the plurality of profile embossing features are either one of a protrusion and a recess feature, whereby heights, in case of protrusion features, or depths in case of recess features, are in a range between 0,1 mm and 2,5 mm.
35. The method for manufacturing according to any one of claims 25 to 34, wherein the sheet of material has a grammage in a range between 10 gsm and 100 gsm and a thickness in a range between 0,02 mm and 1,5 mm.
36. An embossing set-up for manufacturing an embossed sheet of material configured to be folded and obtain a a filtering element configured for an inhalable drug delivery device, and for filtering a mainstream gas flow passing through the filtering element, comprising features of:
a patrix-matrix roller embossing system configured to emboss the sheet of material with a plurality of stripes, in a nip between the patrix-matrix embossing rollers, each stripe comprising corresponding embossing features on each of a patrix embossing roller and a matrix embossing roller of the embossing rollers system, and each embossed stripe being oriented longitudinally on the sheet of material with respect to a feed direction of the sheet of material fed to the nip,
the embossing features comprising:
profile embossing features configured for embossing at least an aerodynamic profile on the sheet of material, the profile embossing features being arranged

according to a radial direction of the stripe on the embossing rollers, the embossed aerodynamic profile being configured to modify in a determined manner flow properties for the mainstream gas flow passing through the filter element by creating a gas flow turbulence occurrence in the filtering element; and

the embossing features further comprising:

radial embossing features configured to delimitate each stripe on opposite radial sides of the stripe, on the patirix-matrix embossing rollers, and further configured to form longitudinal delimitation embossed features that delimitate the embossed stripe on the sheet of material, on opposite longitudinal sides of the embossed stripe,

wherein:

the radial embossing features are further configured to form

a plurality of enclosing walls on the patirix-matrix embossing rollers describing at least an enclosure around one or a plurality of the profile embossing features,

and, for each enclosure,

an enclosure opening in the enclosure connecting the enclosure to a successive enclosure in radial direction of the stripe,

the enclosure having a corresponding maximum enclosure expansion section area in axial direction of the stripe and the enclosure opening having a corresponding enclosure opening constriction section area in the axial direction of the stripe which is smaller than the corresponding maximum enclosure expansion section area, and

to define at least one alternance of the enclosure opening constriction section area and the maximum enclosure expansion section area in the longitudinal direction of the stripe, formed by the enclosure opening and the enclosure respectively, with a cross-section area ratio between the maximum enclosure expansion section area and the enclosure opening constriction section area of the profile in a range from 8:1 to 2:1.

37. The embossing set-up of claim 36, wherein the radial embossing features are further configured to emboss a folding line into the sheet of material.
38. The embossing set-up of any one of claims 36 to 37, wherein a first set of the profile embossing features in a first one of the stripes is designed for a determined gas flow

turbulence in a first longitudinal direction of a corresponding embossed first one of the stripes, and a second set of the profile embossing features in a second one of the stripes adjacent to the first one is designed for the determined gas flow turbulence in a second longitudinal direction of a corresponding embossed second one of the stripes, opposite to the first longitudinal direction.

39. The embossing set-up of any one of claims 36 to 38, wherein the profile embossing features comprise at least one from a list comprising a recess profile embossing feature configured to emboss a corresponding recessed shape in the sheet of material and a protrusion profile embossing feature configured to emboss a corresponding protrusion in the sheet of material.
40. The embossing set-up of any one of claims 36 to 39, wherein the sheet of material comprises any material from a list comprising paper, a cellulose-based material, wool, plant- or animal-based fibrous material.
41. The embossing set-up of any one of the claims 36 to 40, whereby the profile embossing features are further configured to produce a height of the aerodynamic profile that is in a range of 1 to 15 times of a thickness of the sheet of material.
42. The embossing set-up of any one of the claims 36 to 41, further wherein the matrix-rollers and the embossing features are configured for embossing of the sheet of material to be a wallpaper-like embossing producing an uninterrupted and repeating pattern of embossed aerodynamic features and longitudinal delimitation embossed features.