

AN ELECTROSPINNING APPARATUS AND METHOD FOR THE CONTINUOUS PRODUCTION OF FIBRES

Field of the Invention

This invention relates to an apparatus and a method for the continuous production of fibres through electrospinning. More particularly, this invention relates to an electrospinning apparatus, system and method that employ electrospinning techniques to continuously produce nanofibre mats and/or layers.

Prior Art

Electrospinning is a technique that uses electrical force to produce particles and fibres that may be as small as one nanometre. These nanofibres are typically within the submicron range. These particles and fibres may then be accumulated and processed to form nanofibre mats/ layers. These nanofibre mats/ layers have been shown to make extremely effective small particle eliminating filters. In the area of biotechnology, the nanoscale features of these nanofibre mats or layers have been found to promote cell growth and proliferation while in the area of filtration, tissue engineering, battery separators, medical textiles and performance apparel, such electrospun materials have been shown to be advantageous over coarser fibrous materials. As such, efforts are focused on improving the electrospinning processes so that the electrospinning processes may be ramped up to production levels, and so that these nanofibre mats/ layers may be continuously mass-produced in an efficient and cost effective manner.

In a typical electrospinning process, a high voltage electric field is applied between a needle that is in fluid communication with polymer solutions or polymer melts and an exterior collector electrode. A droplet of the polymer solution formed at the tip of the needle is then electrically charged by the applied electric field and subsequently acquires a conical shape known as a Taylor cone. Due to the repulsive electric forces acting at the charged droplet, the Taylor cone becomes unstable causing an expulsion of parts. As the cohesive forces that hold the polymer solution together are overcome, a charged jet erupts from the vertex of the Taylor cone. As the surface of this charged jet is electrically charged, this jet may be attracted to other electrically charged objects of a suitable electrical potential. The charged jet takes flight along a spiral path due to the electrically driven bending instability phenomena. As the charged jet elongates and travels, a solvent present in the jet evaporates during flight,

causing the hardening and drying of the elongated jet until the jet solidifies. This solidified jet forms polymeric fibres that may be accumulated at the exterior electrode.

A proposed method and apparatus used for electrospinning polymer fibres and membranes are disclosed in US Publication No. US 2002/0175449 published on 28 November 2002 in the name of Benjamin Chu et al. This publication discloses of an electrospinning apparatus and method that also includes a post spinning conditioning step for processing the accumulated fibres. Post spinning processors are used to carry out post conditioning steps such as drying or annealing to change the physical characteristics of the accumulated fibres to produce the final membrane. This publication also discloses that the control over the microscopic and macroscopic properties of the charged fluids may be exerted by establishing a second electric field adjacent to the spinnerets whereby the second electric field interacts with the original electric field to manipulate the jet streams towards the desired targets. For the generation of the second electric field, carefully designed probe electrodes or a series of equally spaced plate electrodes are positioned adjacent the spinnerets. In order to exert the necessary control over the multiple jet streams, the interactions between the two electric fields have to be carefully controlled and modulated else the resulting fibres may not be properly formed.

A method and apparatus to control the properties of the electrospun nanofibres are disclosed in US Publication No. US2009/0321997 published on 31 December 2009 in the name of Darrell Reneker et al. This document discloses an apparatus and process for electrospinning fibres in an enclosed chamber. The rate of the solvent evaporation is controlled by changing the partial pressure of water vapour in the air surrounding the jet. This allows the morphology of the fibres to be varied as the fibres are electrospun. It is further disclosed that the humidity in the chamber is carefully monitored and may be either increased using a humidifying device such as a wick or ultrasonic humidifier or alternatively, may be lowered using a cooling device.

US Publication No. 2012/0232224 published on 13 September 2012 in the name of Susumu Honda et al. discloses an electrospinning method and apparatus for producing a fibrous article. As the fibres are being electrospun, the electrospun fibres will acquire static charges. This document discloses of a method whereby an ionizer is used to dissipate the static charges on the electrospun fibres. Ions generated from the ionizer are released either over the fibres as they are electrospun or the ions are released over the formed fibrous article, causing the static charges on the fibres/ fibrous article to dissipate as the ions come into contact the static charges.

Existing methods and apparatuses for electrospinning nanofibres typically involve complex setups or are only able to produce low volumes of fibres. These setups also do not address the issue of flying fibres that result in poorly formed fibre layer and/or mats. Hence, those skilled in the art are constantly looking for ways to devise an apparatus and a method for continuously producing electrospun fibre mats in an efficient and cost effective manner.

Summary of Invention

The above and other problems in the art are solved and an advance in the art is made in accordance with this invention. A first advantage of an apparatus for electrospinning fibres in accordance with this invention is that the apparatus has an inlet vent that is configured to produce ions whereby the produced ions prevent the spun fibres from flying as the fibres are formed through an electrospinning process. By doing so, the formation of the fibres may be controllably focused on a particular area at a collector. A second advantage of an apparatus for electrospinning fibres in accordance with this invention is that the apparatus utilizes two inlet vents that are configured to produce ions to form an ion channel. The formation of this ion channel focuses the formation of electrospun fibres on a particular area at the collector. A third advantage of an apparatus for electrospinning fibres in accordance with this invention is that the apparatus has a chamber that encloses a spinning element, the inlet vent and a fibre collection unit. The spinning element and inlet vent are provided at an upper half of the chamber and the fibre collection unit is provided at a lower half of the chamber. An outlet vent is also provided at the upper half of the chamber for extracting the evaporated solvents and the ions from the chamber, preventing the evaporated solvents and ions from accumulating at the collection unit. A fourth advantage of an apparatus for electrospinning fibres in accordance with this invention is that the apparatus is provided with dispensing and conveying means for controlling the formation of the fibre mat/ layer. Furthermore, a post conditioning mechanism is also provided to control the pressure and/or temperature applied to the fibre layer/ mat during the conditioning process.

In accordance with an embodiment of the invention, an apparatus for electrospinning fibres comprises a first spinning element configured to produce a first charged stream from a first solution and a collection unit for collecting fibres formed from the first charged stream. The apparatus also comprises a first inlet vent positioned adjacent the first spinning element wherein the first inlet vent is configured to supply air and electrically charged air molecules for directing the first charged stream towards the collection unit.

In accordance with another embodiment of the invention, the apparatus further comprises a second inlet vent configured to supply the electrically charged air molecules, wherein the second inlet vent is positioned adjacent the first spinning element. The electrically charged air molecules from the first and second inlet vents form an electrically charged air molecule channel that directs the first charged stream towards the collection unit.

In accordance with yet another embodiment of the invention, the electrically charged air molecules directed through the first inlet vent are charged with the same polarity as that of the first charged stream.

In accordance with another embodiment of the invention, the electrospinning apparatus further comprises a humidity controller device that is connected to the first inlet vent for controlling humidity of the air supplied by the first inlet vent.

In accordance with another embodiment of the invention, the electrospinning apparatus further comprises a chamber that encloses the first spinning element, the first inlet vent and the collection unit. The chamber further comprises an upper half and a lower half with the first spinning element and the first inlet vent being provided at the upper half and the collection unit being provided at the lower half. A first outlet vent may be provided at the upper half of the chamber for extracting gases from the chamber.

In accordance with another embodiment of the invention a system for continuously electrospinning fibres comprises a first spinning element configured to produce a first charged stream from a first solution; a collection unit for collecting fibres formed from the first charged stream; a first inlet vent positioned adjacent the first spinning element wherein the first inlet vent is configured to supply air and electrically charged air molecules for directing the first charged stream towards the collection unit; a first dispensing means for dispensing a first substrate layer across the top surface of the collection unit, wherein fibres formed from the first charged stream are accumulated on the surface of the first substrate layer; and a first conveying means for conveying the first substrate layer.

In accordance with an embodiment of the invention, the electrospinning system further comprises a second dispensing means for dispensing a second substrate layer across the top surface of the accumulated fibres; and a second conveying means for conveying the second substrate layer, the accumulated fibres and the first substrate layer.

In accordance with another embodiment of the invention, the electrospinning system further comprises a conditioning mechanism configured to control the formation of a fibre layer in which the fibre layer is formed between the first substrate layer and the second substrate layer. The conditioning mechanism may comprise a pair of rollers for receiving the
5 first substrate layer, the fibre layer and the second substrate layer.

In accordance with an embodiment of the invention, the conditioning mechanism further comprises a pressure controller that is connected to the pair of rollers for controlling the pressure applied to the first substrate layer, the fibre layer and the second substrate
10 layer by the pair of rollers or a temperature controller that is connected to the pair of rollers for controlling the temperature of the pair of rollers.

In accordance with yet another embodiment of the invention, the conditioning mechanism may comprise a pair of rollers for receiving the first substrate layer, the fibre
15 layer and the second substrate layer; a pressure controller that is connected to the pair of rollers for controlling the pressure applied to the first substrate layer, the fibre layer and the second substrate layer by the pair of rollers; and a temperature controller that is connected to the pair of rollers for controlling the temperature of the pair of rollers.

In accordance with another embodiment of the invention, the electrospinning system further comprises a separation mechanism configured to separate the first substrate layer, the fibre layer and the second substrate layer into separated layers. The separation
20 mechanism may comprise a separator for separating the second substrate layer, the fibre layer and the first substrate layer; a first collection roller for collecting the separated first substrate layer; a second collection roller for collecting the separated second substrate layer;
25 and a fibre collection roller for collecting the separated fibre layer.

In accordance with yet another embodiment of the invention, the collection unit of the electrospinning apparatus may further comprise a container for containing a second solution,
30 the container having: a top surface having a first hole for receiving the first spinning element; and a lid for covering the first hole at the top surface. The collection unit may also further comprise a second solution tank in fluid communication with the first spinning element; and a first pump having an inlet and an outlet. The inlet may be in fluid communication with the container and the outlet may be in fluid communication with the second solution tank with the
35 first pump being utilized to direct the second solution from the container to the second solution tank. The collection unit may further comprise a second pump for directing the

second solution from the second solution tank to the container through the first spinning element when the lid is removed.

5 In accordance with yet another embodiment of the invention, the electrospinning apparatus may further comprise a second spinning element configured to produce a second charged stream from the first solution; and a third inlet vent positioned adjacent the second spinning element. The third inlet vent is configured to supply the electrically charged air molecules for directing the first and the second charged streams towards the collection unit. These electrically charged air molecules may have the same polarity as the charge of the
10 first and second charged streams.

In accordance with another embodiment of the invention, the electrospinning apparatus may comprise a fourth inlet vent configured to supply the electrically charged air molecules, wherein the fourth inlet vent is positioned adjacent the second spinning element
15 such that the electrically charged air molecules from the first, third and fourth inlet vents form electrically charged air molecule channels for directing the first and second charged streams towards the collection unit.

In accordance with another embodiment of the invention, the electrospinning
20 apparatus may further comprise a chamber enclosing the first spinning element, the second spinning element, the first inlet vent, the third inlet vent and the collection unit wherein the chamber further comprises an upper half and a lower half wherein the first spinning element, the second spinning element, the first inlet vent and the third inlet vent are provided at the upper half and the collection unit is provided at the lower half; and a second outlet vent
25 provided at the upper half of the chamber for extracting gases from the chamber.

In accordance with an embodiment of the invention, a method for electrospinning fibres comprises the steps of producing a first charged stream from a first solution using a first spinning element; collecting fibres formed from the first charged stream at a collection
30 unit; and supplying air and electrically charged air molecules from a first inlet vent positioned adjacent the first spinning element, whereby the electrically charged air molecules direct the first charged stream towards the collection unit.

In accordance with an embodiment of the invention, the step of supplying the
35 electrically charged air molecules from the first inlet vent further comprises supplying the electrically charged air molecules from a second inlet vent positioned adjacent the first spinning element such that the air molecules from the first and second inlet vents form an

electrically charged air molecule channel that directs the first charged stream towards the collection unit. The electrically charged air molecules and the first charged stream may be of the same polarity.

5 In accordance with an embodiment of the invention, the method for electrospinning fibres further comprises the step of controlling the humidity of the air using a humidity controller device that is connected to the first inlet vent.

10 In accordance with an embodiment of the invention, the method for electrospinning fibres further comprises the step of enclosing the first spinning element, the first inlet vent and the collection unit using a chamber, wherein the chamber comprises an upper half and a lower half, in which the first spinning element and the first inlet valve is provided at the upper half and the collection unit is provided at the lower half.

15 In accordance with an embodiment of the invention, the method for electrospinning fibres further comprises the step of extracting gases from the chamber using a first outlet vent provided at the upper half of the chamber.

20 In accordance with an embodiment of the invention, the method for electrospinning fibres further comprises the steps of dispensing a first substrate layer across the top surface of the collection unit using a first dispensing means, wherein fibres formed from the first charged stream are accumulated on the surface of the first substrate layer; and conveying the first substrate layer and the accumulated fibres towards a second dispensing means.

25 In accordance with this embodiment of the invention, the method for electrospinning fibres further comprises the steps of dispensing a second substrate layer across the top surface of the accumulated fibres using the second dispensing means; and conveying the second substrate layer, the accumulated fibres and the first substrate layer towards a conditioning mechanism.

30 In accordance with this embodiment of the invention, the method for electrospinning fibres further comprises the step of controlling the formation of a fibre layer using the conditioning mechanism in which the fibre layer is formed between the first substrate layer and the second substrate layer.

35 In accordance with this embodiment of the invention, the method for electrospinning fibres further comprises the steps of receiving of the first substrate layer, the fibre layer and

the second substrate layer using a pair of rollers; and controlling a pressure applied to the first substrate layer, the fibre layer and the second substrate layer by the pair of rollers.

15 In accordance with this embodiment of the invention, the method for electrospinning fibres further comprises the steps of receiving of the first substrate layer, the fibre layer and the second substrate layer using a pair of rollers; and controlling a temperature applied to the first substrate layer, the fibre layer and the second substrate layer by the pair of rollers.

10 In accordance with another embodiment of the invention, the method for electrospinning fibres further comprises the steps of receiving of the first substrate layer, the fibre layer and the second substrate layer using a pair of rollers; controlling a pressure applied to the first substrate layer, the fibre layer and the second substrate layer by the pair of rollers; and controlling a temperature applied to the first substrate layer, the fibre layer and the second substrate layer by the pair of rollers.

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In accordance with an embodiment of the invention, the method for electrospinning fibres further comprises the steps of conveying the layers of the first substrate, the fibre layer and the second substrate towards a separation mechanism; and separating the layers of the first substrate, the fibre layer and the second substrate into separated layers.

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In accordance with this embodiment of the invention, the steps of separating the layers further comprises the steps of: collecting the separated first substrate layer using a first collection roller; collecting the separated second substrate layer using a second collection roller; and collecting the separated fibre layer using a fibre collection roller.

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In accordance with an embodiment of the invention, the method for electrospinning fibres further comprises the steps of stopping the first spinning element from producing charged streams after a first period; removing a lid from a top surface of the collection unit revealing a first hole wherein the collection unit further comprises a container for containing a second solution; and receiving the first spinning element in the first hole. The second solution is pumped from the container to a second solution tank; and pumped from the second solution tank to the container through the first spinning element.

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In accordance with another embodiment of the invention, the method for electrospinning fibres further comprises the steps of producing a second charged stream from a first solution using a second spinning element; and supplying the electrically charged air molecules from a third inlet vent positioned adjacent the second spinning element,

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whereby the electrically charged air molecules direct the first and second charged streams towards the collection unit. The electrically charged air molecules and the first and second charged streams may be of the same polarity.

5 In accordance with an embodiment of the invention, the method for electrospinning fibres further comprises the steps of supplying the electrically charged air molecules from a fourth inlet vent positioned adjacent the second spinning element such that the electrically charged air molecules from the first, third and fourth inlet vents form electrically charged air molecule channels for directing the first and second charged streams towards the collection
10 unit.

Brief Description of the Drawings

The above advantages and features of a method and apparatus in accordance with
15 this invention are described in the following detailed description and are shown in the drawings:

Figure 1 illustrating an apparatus for electrospinning fibres in accordance with an embodiment of this invention;

20 Figure 2 illustrating an apparatus having two spinning elements for electrospinning fibres in accordance with an embodiment of this invention;

Figure 3 illustrating a setup for continuously electrospinning large volumes of fibres in accordance with an embodiment of this invention;

25 Figure 4 illustrating a scaled up setup of the apparatus of Figure 3 in accordance with an embodiment of this invention;

Figure 5 illustrating a collection unit in accordance with an embodiment of this invention;

Figure 6 illustrating a collection unit aligned with a spinning element arrangement in accordance with an embodiment of this invention;

30 Figure 7 illustrating a setup for cleaning the spinning elements in accordance with an embodiment of this invention;

Figure 8 illustrating a flowchart of a method for continuously electrospinning fibres in accordance with an embodiment of this invention;

Figure 9 illustrating a flowchart of a method for collecting the fibres formed from the electrospinning process in accordance with an embodiment of this invention;

Figure 10 illustrating a flowchart of a method for controlling the formation of a fibre layer in accordance with an embodiment of this invention;

5 Figure 11 illustrating a flowchart of a method for cleaning the spinning elements in accordance with an embodiment of this invention; and

Figures 12A-12H illustrating SEM photographs of a fibre layer formed in accordance with an embodiment of this invention when the temperature applied by a conditioning mechanism is varied and when the applied pressure is maintained as a constant.

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Detailed Description

This invention relates to an apparatus and a method for the continuous production of fibres through electrospinning. More particularly, this invention relates to an electrospinning
15 setup and a method that addresses the issues of flying fibres and employs various techniques to continuously produce fibre mats and/or layers. Still more particularly, this invention may be scaled accordingly to produce large volumes of electrospun fibres efficiently and cost effectively.

20 Figure 1 illustrates an electrospinning apparatus in accordance with an embodiment of this invention. Electrospinning apparatus 100 includes spinning element 105, collection unit 130, and inlet vents 120, 121. High voltage power supply 145 is connected between spinning element 105 and collection unit 130 for creating an electric field between spinning
25 element 105 and collection unit 130. Solution tank 140 which contains a polymer solution or a polymer melt is in fluid communication with spinning element 105. The polymer solution in solution tank 140 may comprise PVDF (Polyvinylidene fluoride), PES (Polyethersulfone), PS (Polysulfone), PAN (Polyacrylonitrile), PET (Polyethylene terephthalate), PP (Polypropylene), PVC (Polyvinyl Chloride), or PBI (Polybenzimidazole). One skilled in the art will recognize that other types of polymer solutions may be used without departing from this invention.
30 Inlet vents 120 and 121 are connected to air flow generator 135. In an embodiment of this invention, air flow generator 135 may also include an ionizer for generating ions or electrically charged air molecules. These generated ions may comprise solely of either negative ions or positive ions. If required, the ionizer may also be used to generate a mixture of positive and negative ions. The exact workings of the ionizer is omitted for brevity.

As shown in Figure 1, chamber 131 is used to enclose spinning element 105, collection unit 130 and inlet vents 120, 121.

As illustrated in Figure 1, solution tank 140 is used to supply spinning element 105 with the polymer solution. A pump such as an air pump (not shown) connected to solution tank 140 may be used to control the rate at which the polymer solution is extruded out of spinning element 105. When a sufficiently high voltage is applied to spinning element 105 using power supply 145, the polymer solution at the tip of spinning element 105 becomes electrically charged and acquires a conical shape known as a Taylor cone. Once a critical point is achieved, charged jet stream 110 will erupt from the surface of the Taylor cone towards collection unit 130. As charged jet stream 110 elongates and travels, a solvent present in charged jet stream 110 evaporates during flight causing jet stream 110 to harden and dry. Simultaneously, during flight, the mode of current flow in charged jet stream 110 changes from ohmic current flow to convective current flow. In the convective current flow phase, charged jet stream 110 elongates due to a whipping process known as electrostatic repulsion. The elongation and thinning of charged jet stream 110 then leads to the formation of nanometre-sized diameter fibres 115. Fibres 115 are then accumulated at collection unit 130 forming accumulated fibres 116. As described above, as the surface of charged jet stream 110 is electrically charged, charged jet stream 110 may either be attracted to or repulsed by other electrically charged objects of a suitable electrical potential. This randomized electrical attraction causes charged jet stream 110 to deviate away from collection unit 130. When this occurs, the formed fibres will fall randomly around the base of chamber 131. The formation of these flying fibres reduces the efficiency of the apparatus, as a portion of the formed fibres, that is the flying fibres, will be formed around collection unit 130 and not on a designated area on collection unit 130. Furthermore, when another spinning element is positioned adjacent spinning element 105, fibres formed from the charged jet streams of each respective spinning element may end up clumping together; forming coagulated lumps of fibre that eventually drop down towards collection unit 130.

Inlet vents 120, 121 address this issue as these inlet vents are configured to supply a steady stream of ions to direct charged jet stream 110 towards collection unit 130. By doing so, fibres 115 may be efficiently accumulated at a designated area on collection unit 130. As illustrated in Figure 1, inlet vents 120, 121 are positioned adjacent spinning element 105. One skilled in the art will recognize that inlet vents 120, 121 may be placed at any other positions adjacent spinning element 105 without departing from this invention. Air flow generator 135 is used to generate air flow and ions 126 which are directed into chamber 131 through inlet vents 120, 121. The nozzles of inlet vents 120, 121 are pointed towards

the direction of collection unit 130 so that the supplied air and ions 126 will flow towards collection unit 130. Ions 126 react with the charged surface of jet stream 110, directing charged jet stream 110 towards a designated area on collection unit 130. In an embodiment of the invention, charged stream 110 is positively charged by power supply 145 and air flow generator 135 is configured to generate ions 126 that are positively charged as well. Positively charged ions 126 emitting from inlet vents 120, 121, repel positively charged jet stream 110 downwards, towards collection unit 130 thereby preventing the occurrence of flying fibres. In another embodiment of the invention, charged stream 110 may be negatively charged by power supply 145. In this embodiment, air flow generator 135 may then be configured to generate ion 126 that are negatively charged so that negatively charged ions 126 may be used to repel negatively charged jet stream 110. In the embodiment illustrated in Figure 1, inlet vents 120 and 121 are illustrated as being positioned on either side of spinning element 105. As ions 126 are continuously being produced through inlet vents 120 and 121, this creates ion channel 127. Ion channel 127 creates a pathway that directs charged stream 110, which is contained within ion channel 127, towards collection unit 130. Whenever charged stream 110 deviates from the path created by ion channel 127, the repulsion between ions 126 (that form the walls of ion channel 127) and charged stream 110 causes charged stream 110 to return to the pathway created within ion channel 127.

In another embodiment of the invention, air generator 135 may further comprise a humidity controller device such as a humidifier for controlling the humidity of the air molecules that are introduced into chamber 131 through inlet vents 120 and 121. The humidity of the air in chamber 131 affects the rate of evaporation of the solvent from charged jet stream 110. When the humidity in chamber 131 increases, this causes the rate of solvent evaporation to reduce and vice versa, when the humidity in chamber 131 decreases, this causes the rate of solvent evaporation to increase. Therefore, the thickness of the electrospun fibres may be altered accordingly by controlling the humidity produced by air generator 135.

Chamber 131 may be divided into two sections, upper section A and lower section B. Outlet vent 132, positioned within chamber 131, is used to extract evaporated solvents and ions 126 from chamber 131. Outlet vent 132 may be connected to an air extraction device such as an exhaust fan, a suction pump or any other such devices that may be used for extracting air from chamber 131. In an embodiment of the invention, outlet vent 132 is positioned within upper section A. Outlet vent 132 ensures that ions 126 do not gather or collect at collection unit 130 by extracting ions 126 from chamber 131 before ions 126 reach collection unit 130. If ions 126 are allowed to accumulate at collection unit 130, this is

deleterious, as the ions accumulated at collection unit 130 will repel fibre 115 away from collection unit 130, thereby reducing the efficiency of apparatus 100. In another embodiment of the invention, the length of upper section A corresponds to a portion of the charged stream when the charge at the surface of the charged stream is undergoing ohmic flow. In the same embodiment, the length of lower section B corresponds to a portion of the charged stream when the charge at the surface of the charged stream is undergoing convective flow.

Figure 2 illustrates apparatus 200 which includes all the elements of apparatus 100 with the addition of a second spinning element that is spinning element 205 and the addition of a third inlet vent that is inlet vent 122. Similar to spinning element 105 and inlet vents 120, 121, spinning element 205 is also in fluid communication with solution tank 140 and inlet vent 122 is also connected to air generator 135. Spinning element 205, which is positioned adjacent inlet vent 120 and 122, is also used to generate charged stream 110 that subsequently solidifies to form fibres 115. Inlet vents 120 and 122 are used to convey ions 126 from air generator 135. Ion 126 from inlet vents 120 and 122 direct charged stream 110 from spinning element 205 towards collection unit 130. By using two spinning elements, that is spinning elements 105 and 205 in conjunction with inlet vents 120-122, apparatus 200 is able to produce a larger quantity of fibres resulting in a thicker fibre mat 116. Furthermore, due to this configuration, apparatus 200 is able to prevent the formed fibres from clumping together; thereby avoiding the formation of coagulated lumps of fibre that eventually drop down towards collection unit 130. Figure 2 shows that apparatus 100 may be altered to produce larger amounts of fibre 115 by increasing the number of spinning elements and inlet vents accordingly.

Figure 3 illustrates system 300 that may be used to continuously produce nanofibre mats from electrospun fibres. System 300, which is a scaled up version or a production scale version of apparatus 100 and 200, utilizes the operating principles of apparatus 100 and 200 as illustrated in detail in Figures 1 and 2 with the addition of a few additional components. System 300 is enclosed within chamber 131 and outlet vents 132 are provided at an upper section of chamber 131 for extracting gases and ions from chamber 131. One skilled in the art will recognize that any number of outlet vents 132 may be used without departing from this invention. In this embodiment, eleven spinning elements 302 and twelve inlet vents 301 are utilized. Each inlet vent is positioned adjacent to each spinning element as discussed in relation to Figures 1 and 2. One skilled in the art will recognize that any number of spinning elements and inlet vents may be used without departing from this invention. Inlet vents 301, which are connected to air generator 135 direct electrically charged air molecules or ions from air generator 135 into chamber 131, towards collection

unit 130. Spinning elements 302, which are in fluid communication with solution tank 140, may be used to produce charged streams 110 that are attracted to collection unit 130. The ions from inlet vents 301 assist in ensuring that the plurality of charged stream 110 stays on course and remains directed towards collection unit 130, thereby preventing the occurrence of flying fibres.

Roller 305 is used to dispense substrate 306 over a top surface of collection unit 130. Electrospun fibres 115 will accumulate on a surface of substrate 306 as fibres 115 are being electrospun. Substrate 306 is also connected to roller 325 which collects and gathers substrate 306 after substrate 306 has been used. The thickness of accumulated fibres 116 on the surface of substrate 306 may be controlled by varying the rate of rotation of rollers 305 and 325. For example, if the thickness of accumulated fibres 116 is to be increased, the rotation rate of rollers 305 and 325 will be slowed down and the thickness of accumulated fibres 116 is to be decreased, the rotation rate of rollers 305 and 325 will be increased accordingly. This arrangement of rollers 305 and 325 allows accumulated fibres 116 to be conveyed through the system as illustrated in Figure 3. Roller 310 is used to dispense layer 311 on a top surface of accumulated fibres 116 as the layers of substrate 306 and accumulated fibres 116 pass through guider 312. Layer 311 is also connected to roller 315 which collects and gathers layer 311 after layer 311 has been used. In this embodiment, substrate 306 comprises of a PET (Polyethylene terephthalate) while layer 311 comprises of an aluminium foil layer. Substrate 306 may comprise of other types of polymeric porous support materials. Substrate 306 may also comprise of non-woven fabrics if the selected fabric has sufficient mechanical strength to be used as a substrate. Aluminium foil was selected as the material for layer 311 as aluminium foil has excellent heat transferring characteristics. Furthermore, the foil is able to partially protect the membrane from physical deformations as the membrane passes through roller 330. One skilled in the art will recognize that other types of materials may be used as substrate 306 and as layer 311 without departing from this invention.

After the layers of substrate 306, accumulated fibres 116 and layer 311 have passed through guider 312, a multi-layered structure is produced, with substrate 306 being the first layer, accumulated fibres 116 being the middle layer (i.e. the second layer) and layer 311 being the third layer. This multi-layered structure is then conveyed to rollers 330 for a conditioning process. Rollers 330 are connected to controller device 335 that may control the pressure and/or the temperature that may be applied by rollers 330 to the multi-layered structure. In an embodiment of the invention, the pressure applied by rollers 330 on the multi-layered structure is maintained between 2 and 5 Bar. It was found that if the

temperature of rollers 330 were to be increased beyond 175°C, the accumulated fibres 116 layer in the multi-layered structure will melt and coagulate together when cooled, producing a non-porous fibre layer that may not be used in nanofibre applications. It was also found that if the temperature of rollers 330 were decreased below 25°C, the strands of fibre in accumulated fibres 116 layer in the multi-layered structure will not affix to one another. As such, for the formation of a fibre layer for nanofibre applications, rollers 330 are maintained at a temperature between 70°C and 160°C. In a preferred embodiment of the invention, rollers 330 are maintained at a temperature range between 150°C and 160°C and rollers 330 are configured to apply 3 Bars of pressure. Once rollers 330 have conditioned the multi-layered structure, a conditioned multi-layered structure 340 is produced, whereby nanofibre layer 116A is formed between substrate 306 and layer 311. Separator 341 is used to separate layer 311, nanofibre layer 116A and substrate 306 into three individual layers. Roller 320 is used to collect and gather nanofibre layer 116A, roller 315 is used to collect and gather layer 311 and roller 325 is used to collect and gather substrate 306. This mechanical separation process divides multi-layered structure 340 into three individual layers that are collected by their respective rollers. Nanofibre layer 116A collected at roller 320 may then be removed from system 300 to be used in further applications.

Figure 4 illustrates system 400 which is a scaled up version of system 300 as illustrated in Figure 3. System 400 shows that the amount of electrospun fibres 115 may be increased by utilizing more rows of spinning elements and inlet vents accordingly. The rows of spinning elements and inlet vents may be connected in parallel to the solution tank and to the air generator. The collection unit may then be used to collect all the fibres that are electrospun by the system. The fibres accumulated at the collection unit may then be conveyed, processed and collected as illustrated in Figure 3 and as described above.

Periodically, system 300, as illustrated in Figure 3, may be paused to allow spinning elements 302 to be cleaned and unblocked through a cleaning process. The apparatuses involved in the cleaning of spinning elements 302 are illustrated in Figures 5-7. An enlarged view of collection unit 130 is illustrated in Figure 5. Collection unit 130 comprises container 510 that is used to contain solution 520. The top surface of container 510 comprises a number of holes 515 which are covered by lid 505. The number of openings provided at holes 515 corresponds to the number of spinning elements that are to be cleaned. However, one skilled in the art will recognize that the number of openings provided at holes 515 may exceed the number of spinning elements in the system without departing from this invention. Lid 505 prevents electrospun fibres 115 from entering container 510 during the electrospinning process. Furthermore, lid 505 also ensures that a flat uniformed surface is

arranged to be facing the plurality of spinning elements during the accumulation of electrospun fibres 115. This means that if lid 505 were not used, it would not be possible for the entire top surface of container 130 to be maintained at an even and uniformed potential. This would result in the uneven accumulation of electrospun fibres at collection unit 130.

5 During the cleaning process, lid 505 would be removed, exposing holes 515. Holes 515 are provided on the top surface of container 510 such that each opening in holes 515 aligns with each spinning element of row 605. The inlet vents on row 605 have been omitted for brevity as these inlet vents are not utilized during the cleaning process. After lid 505 has been removed, spinning element row 605 is lowered towards container 510 as shown by arrow

10 610. Figure 7 shows that once row 605 has been lowered, each spinning element in row 605 will have been received by a corresponding opening in holes 515. At this stage, all the tips of the spinning elements in row 605 are submerged in solution 520. Pump 706, which is in fluid communication with container 510, pumps solution 520 from container 510 towards solution tank 711. Arrows 705 and 710 illustrate the flow of solution 520 from container 510

15 to pump 706 and subsequently to solution tank 711 respectively. Pump 716, which is in fluid communication with solution tank 711 and spinning element row 605, pumps solution 520 from solution tank 711 into container 510 via the spinning elements in row 605. Arrows 715, 720 and 725 illustrate the flow of solution 520 from solution tank 711 to pump 716, from pump 716 to row 605 and subsequently through the spinning elements of row 605 into

20 container 510 respectively. Solution 520 unblocks and clears any polymer solutions that may be stuck in or clogging the spinning elements as solution 520 is expelled via each spinning element in row 605 through the use of pump 716. Fresh solution 520 is supplied by solution tank 711 ensuring that solution 520 contained within container 510 will not become overly polluted as the spinning elements are cleared of their blockages and/or obstructions.

25 Once the cleaning process has ended, lid 505 will be positioned again over holes 515 of container 510. The unclogged spinning elements in system 300 may then be used to continuously produce electrospun fibres. Pump 706 and 716 may comprise of recirculation pumps. One skilled the art will recognize that other types of pumps may be used without departing from this invention. Solution 520 may comprise solvents such as

30 Dimethylacetamide (DMAc), N-Methyl-2-pyrrolidone (NMP), Dimethylformamide (DMF), acetone, N-hexane, toluene, ethanol, methanol, or formic acid.

A method of continuously producing electrospun fibres in accordance with an embodiment of this invention is illustrated in Figure 8. Process 800 for the continuous

35 electrospinning of fibres begins at step 810. At this step, an air flow generator is used to supply air and ions or electrically charged air molecules for use in this electrospinning system. The air and ions are supplied to the system through inlet vents that are positioned

adjacent to each spinning element. In another embodiment of the invention, a humidity controller device may be connected to the air flow generator. This humidity controller device may be used to vary the humidity of the air flow produced by the air flow generator.

5 At step 815, a power supply unit is used to apply a high voltage to each spinning element that is in fluid communication with a polymer solution. When the polymer solution at the tip of the spinning element becomes charged, a charged jet stream will erupt from the spinning element towards the direction of a collection unit. This charged jet stream will be attracted towards the collection unit as the collection unit will be charged to an opposing
10 polarity relative to the charge applied to the spinning element. The charged jet stream will also be directed towards the collection unit by the ions supplied through the inlet vents. The ions supplied by the inlet vents are directed to flow towards the direction of the collection unit as the nozzles of the inlet vents are directed towards the collection unit. This stream of ions will repel the charged stream towards the collection unit, preventing the charged stream from
15 deviating away from the collection unit. By doing so, the formations of flying fibres are prevented during electrospinning process 800.

As the charged stream solidifies, the charged stream forms elongated fibres that twist and bend, that finally accumulates on the collection unit. At step 820, the formed electrospun
20 fibres accumulated on the collection unit are collected. After fibres have been continuously produced for a given time period, step 825 determines if the electrospinning process may be paused for the spinning elements to be subjected to a cleaning process at step 830. If step 825 determines that the electrospinning process may continue, step 825 then proceeds to step 810 and process 800 repeats itself. In certain embodiments of the invention, the
25 spinning elements are subjected to the cleaning process immediately after the spinning process has been completed. In another embodiment of the invention, the entire electrospinning apparatus may be enclosed within a chamber with the spinning elements and inlet vents being provided at an upper half of the chamber while the collection unit is being provided at a lower half of the chamber. An outlet vent positioned at the upper half of
30 the chamber may be used to extract evaporated solvents and the ions from the chamber, thereby preventing the ions from accumulating with the fibres at the surface of the collection unit.

 An embodiment of process 820, which is the step of collecting the accumulated fibres,
35 is illustrated in Figure 9. Process 820 begin at step 910 whereby a first substrate such as a PET substrate is dispensed over the top surface of the collection unit. As the first substrate layer covers the top surface of the collection unit, the electrospun fibres from the system will

accumulate on the surface of the first substrate instead of the top surface of the collection unit. The accumulation of the electrospun fibres on the surface of the first substrate layer occurs at step 915 of process 820. At step 920, the first substrate layer together with the accumulated fibres are conveyed towards a second dispensing means. The second
5 dispensing means, which may include a roller, may be used to dispense a second substrate, such as a layer of aluminium foil, over the top surface of the accumulated fibres. This occurs at step 925. After the second substrate has been laid over the accumulated fibres, this results in a multi-layered structure that comprises of the second substrate as the top layer, the accumulated fibres as the middle layer and the PET substrate forming the bottom layer.
10 This multi-layered structure is then conveyed at step 930 towards a conditioning mechanism. The formation of a fibre layer from the middle layer that comprises of the accumulated fibres is carefully controlled at step 935. After the fibre layer has been formed, process 820 then proceeds to convey the multi-layered structure to a separation mechanism at step 940. All the three layers are separated at this step into three individual layers. These three
15 separated layers are then gathered using three separate collection rollers at step 945. Process 820 then ends at step 950.

An embodiment of process 935 is illustrated in Figure 10. In this embodiment, the conditioning mechanism comprises a pair of rollers that are connected to a controller device.
20 The controller device may be used to control the pressure and/or the temperature applied by the rollers to the multi-layered structure. During the conditioning process, a pair of rollers are used to receive the multi-layered structure. This occurs at step 1010 of process 935. The rollers are used to apply a pressure and/or to heat the multi-layered structure to a predetermined pressure and/or temperature. In an embodiment of the invention, the
25 pressure applied by the rollers on the multi-layered structure is maintained between 0 and 80 Bar. It was found that if the temperature of the rollers were to be increased beyond 300°C, the accumulated fibre layer in the middle of the multi-layered structure will melt and coagulate together when cooled, producing a non-porous fibre layer that may not be used in nanofibre applications. It was also found that if the temperature of the rollers were
30 decreased below 25°C, the strands of fibre in the accumulated fibre layer in the multi-layered structure will not affix to one another. As such, for the formation of a fibre layer for nanofibre applications, the rollers should be maintained at a temperature between 25°C and 300°C. Once this the fibre layer has been formed by process 935, process 935 ends at step 1020.

35 An embodiment of cleaning step 830 is illustrated in Figure 11. At step 1110, the supply of the charged stream is paused by switching of the supply of the high voltage to the spinning element. The supply of air and ions from the inlet vents are also paused at step

1115. Once this is done, process 830 then proceeds to step 1120. A lid is removed from the collection unit thereby revealing openings for receiving the spinning elements. The number of openings in the collection unit depends on the number of spinning elements that are used for electrospinning. For example, if the system utilizes only one spinning element, then only one opening has to be provided at the collection unit. The collection unit also includes a container that contains a solution such as a solvent for clearing blockages in the spinning element. At this step, the spinning elements are lowered into the openings with each of the tips of the spinning elements being immersed into the solution. At step 1125, the solution in the container is pumped into a solution tank using a pump. At step 1130, another pump is then used to pump solution from the solution tank into the container, through the spinning elements. Process 830 determines at step 1135 whether all blockages at the spinning element have been cleared. If the blockages have not been cleared, process 830 proceeds to step 1125 and repeats the pumping process. This process of pumping the solution through the spinning element is continuously repeated until all blockages in the spinning element have been cleared. Once process 830 determines at step 1135 that the spinning element has been cleared of blockages or clogs, process 830 then proceeds to step 1140.

Example 1

The following experimental results disclose of the formation of the nanofibre layer when certain parameters in the conditioning mechanism are varied. One skilled in the art will realize that the results set out below are not exhaustive and only provide an indicative performance of an embodiment of this invention.

In this example, the polymer that was utilized for the electrospinning process is PVDF (Polyvinylidene fluoride). The temperature applied by the rollers during the conditioning process were varied between 70°C and 175°C while the pressure applied by the rollers were maintained constant at 3 Bar.

	Temperature (°C)	Pressure (Bar)	Result
1.	70	3	See Figure 12A
2.	90	3	See Figure 12B
3.	110	3	See Figure 12C
4.	130	3	See Figure 12D
5.	150	3	See Figure 12E

6.	160	3	See Figure 12F
7.	170	3	See Figure 12G
8.	175	3	See Figure 12H

As illustrated in Figures 12A-12H, it is shown that as the temperature applied by the rollers during the conditioning process increases, the formed fibre layer become denser. Figures 12A-12B show that when the applied temperature is between 70°C and 90°C, the fibres in the formed fibre layer are not tightly packed together. In this condition, there is the risk that the fibre layer may fall apart when in use. Figures 12C-12F show that when the applied temperature range is between 110°C and 160°C, more adjacent fibres have begun to adhere together forming a more solid nanofibre layer as the applied temperature increases. However, once the applied temperature exceeds 170°C, the fibre structures begin to breakdown and melt, forming a coagulated mess as can be seen in Figures 12G-12H. From these results, it is shown that in order to produce a porous nanofibre layer with tightly formed layers whereby the fibres have firmly adhered to one another, the temperature range during the conditioning process should be maintained between 150°C and 160°C.

The above is a description of an apparatus and a method for electrospinning fibres whereby electrically charged air molecules are used to direct a charged stream from a spinning element towards a collection unit thereby preventing the occurrence of flying fibres that may reduce the efficiency of the electrospinning process and/or the formation of clumped fibres. Additionally, the apparatus and method described above utilizes outlet vents to extract the ions and evaporated solvents from a chamber enclosing the apparatuses. It is foreseen that those skilled in the art can and will design alternative embodiments of this invention as set forth in the following claims.

CLAIMS:

1. An apparatus for electrospinning fibres comprising:

a first spinning element configured to produce a first charged stream from a first solution;

a collection unit for collecting fibres formed from the first charged stream; and

a first inlet vent positioned adjacent the first spinning element wherein the first inlet vent is configured to supply air and electrically charged air molecules for directing the first charged stream towards the collection unit.

2. The apparatus according to claim 1 further comprising:

a second inlet vent configured to supply the electrically charged air molecules, wherein the second inlet vent is positioned adjacent the first spinning element such that the electrically charged air molecules from the first and second inlet vents form an electrically charged air molecule channel for directing the first charged stream towards the collection unit.

3. The apparatus according to claim 1 wherein the electrically charged air molecules and the first charged stream have the same polarity.

4. The apparatus according to claim 1 further comprising:

a humidity controller device that is connected to the first inlet vent for controlling humidity of the air supplied by the first inlet vent.

5. The apparatus according to claim 1 further comprising:

a chamber enclosing the first spinning element, the first inlet vent and the collection unit wherein the chamber further comprises an upper half and a lower half wherein the first spinning element and the first inlet vent are provided at the upper half and the collection unit is provided at the lower half.

6. The apparatus according to claim 5 further comprising:

a first outlet vent provided at the upper half of the chamber for extracting gases from the chamber.

7. A system for continuously electrospinning fibres comprising:

a first spinning element configured to produce a first charged stream from a first solution;

a collection unit for collecting fibres formed from the first charged stream;

a first inlet vent positioned adjacent the first spinning element wherein the first inlet vent is configured to supply air and electrically charged air molecules for directing the first charged stream towards the collection unit;

5 a first dispensing means for dispensing a first substrate layer across the top surface of the collection unit, wherein fibres formed from the first charged stream are accumulated on the surface of the first substrate layer; and

a first conveying means for conveying the first substrate layer.

10 8. The system according to claim 7 further comprising:

a second dispensing means for dispensing a second substrate layer across the top surface of the accumulated fibres; and

a second conveying means for conveying the second substrate layer, the accumulated fibres and the first substrate layer.

15 9. The system according to claim 8 further comprising:

a conditioning mechanism configured to control the formation of a fibre layer in which the fibre layer is formed between the first substrate layer and the second substrate layer.

20 10. The system according to claim 9 wherein the conditioning mechanism comprises:

a pair of rollers for receiving the first substrate layer, the fibre layer and the second substrate layer.

25 11. The system according to claim 10 wherein the conditioning mechanism further comprises:

a pressure controller that is connected to the pair of rollers for controlling a pressure applied to the first substrate layer, the fibre layer and the second substrate layer by the pair of rollers wherein the pressure applied is between 2 and 3 Bars.

30 12. The system according to claim 10 wherein the conditioning mechanism further comprises:

a temperature controller that is connected to the pair of rollers for controlling a temperature of the pair of rollers wherein the temperature is between 150°C and 35 160°C .

13. The system according to claim 9 wherein the conditioning mechanism further comprises:

a pair of rollers for receiving the first substrate layer, the fibre layer and the second substrate layer;

5 a pressure controller that is connected to the pair of rollers, for controlling a pressure applied to the first substrate layer, the fibre layer and the second substrate layer by the pair of rollers; and

a temperature controller that is connected to the pair of rollers, for controlling a temperature of the pair of rollers.

10 14. The system according to claim 9 further comprising:

a separation mechanism configured to separate the first substrate layer, the fibre layer and the second substrate layer into separated layers.

15 15. The system according to claim 14 wherein the separation mechanism comprises:

a separator for separating the second substrate layer, the fibre layer and the first substrate layer;

a first collection roller for collecting the separated first substrate layer;

a second collection roller for collecting the separated second substrate layer;

20 and

a fibre collection roller for collecting the separated fibre layer.

16. The apparatus according to claim 1 wherein the collection unit comprises:

a container for containing a second solution, the container having,

25 a top surface having a first hole for receiving the first spinning element;

and

a lid for covering the first hole at the top surface.

17. The apparatus according to claim 16 further comprising:

30 a second solution tank in fluid communication with the first spinning element;

and

a first pump having an inlet and an outlet, the inlet being in fluid communication with the container and the outlet being in fluid communication with the second solution tank, the first pump for directing the second solution from the container to the second solution tank.

18. The apparatus according to claim 17 further comprising:

a second pump for directing the second solution from the second solution tank to the container through the first spinning element when the lid is removed.

19. The apparatus according to claim 1 further comprising:

5 a second spinning element configured to produce a second charged stream from the first solution; and

a third inlet vent positioned adjacent the second spinning element wherein the third inlet vent is configured to supply the electrically charged air molecules for directing the first and the second charged streams towards the collection unit.

10 20. The apparatus according to claim 19 wherein the electrically charged air molecules and the first and second charged streams have the same polarity.

21. The apparatus according to claim 19 further comprising:

15 a fourth inlet vent configured to supply the electrically charged air molecules, wherein the fourth inlet vent is positioned adjacent the second spinning element such that the electrically charged air molecules from the first, third and fourth inlet vents form electrically charged air molecule channels for directing the first and second charged streams towards the collection unit.

20 22. The apparatus according to claim 19 further comprising:

a chamber enclosing the first spinning element, the second spinning element, the first inlet vent, the third inlet vent and the collection unit wherein the chamber further comprises an upper half and a lower half wherein the first spinning element, the second spinning element, the first inlet vent and the third inlet vent are provided at the upper half and the collection unit is provided at the lower half; and

25 a second outlet vent provided at the upper half of the chamber for extracting gases from the chamber.

30 23. A method for electrospinning fibres comprising:

producing a first charged stream from a first solution using a first spinning element;

collecting fibres formed from the first charged stream at a collection unit; and

35 supplying air and electrically charged air molecules from a first inlet vent positioned adjacent the first spinning element, whereby the electrically charged air molecules direct the first charged stream towards the collection unit.

24. The method according to claim 23 wherein the step of supplying the electrically charged air molecules from the first inlet vent further comprises the step of:

supplying the electrically charged air molecules from a second inlet vent positioned adjacent the first spinning element such that the air molecules from the first and second inlet vents form an electrically charged air molecule channel that directs the first charged stream towards the collection unit.

25. The method according to claim 23 wherein the electrically charged air molecules and the first charged stream have the same polarity.

26. The method according to claim 23 further comprising the step of:

controlling humidity of the air using a humidity controller device that is connected to the first inlet vent.

27. The method according to claim 23 further comprising the step of:

enclosing the first spinning element, the first inlet vent and the collection unit using a chamber, wherein the chamber comprises an upper half and a lower half, in which the first spinning element and the first inlet valve is provided at the upper half and the collection unit is provided at the lower half.

28. The method according to claim 27 further comprising the step of:

extracting gases from the chamber using a first outlet vent provided at the upper half of the chamber.

29. The method according to claim 23 further comprising the steps of:

dispensing a first substrate layer across the top surface of the collection unit using a first dispensing means, wherein fibres formed from the first charged stream are accumulated on the surface of the first substrate layer; and

conveying the first substrate layer and the accumulated fibres towards a second dispensing means.

30. The method according to claim 29 further comprising the steps of:

dispensing a second substrate layer across the top surface of the accumulated fibres using the second dispensing means; and

conveying the second substrate layer, the accumulated fibres and the first substrate layer towards a conditioning mechanism.

31. The method according to claim 30 further comprising the step of:

controlling the formation of a fibre layer using the conditioning mechanism in which the fibre layer is formed between the first substrate layer and the second substrate layer.

5

32. The method according to claim 31 wherein the controlling of the formation of the fibre layer further comprises the steps of:

receiving of the first substrate layer, the fibre layer and the second substrate layer using a pair of rollers; and

10 controlling a pressure applied to the first substrate layer, the fibre layer and the second substrate layer by the pair of rollers.

33. The method according to claim 31 wherein the controlling of the formation of the fibre layer further comprises the steps of:

15 receiving of the first substrate layer, the fibre layer and the second substrate layer using a pair of rollers; and

controlling a temperature applied to the first substrate layer, the fibre layer and the second substrate layer by the pair of rollers.

20 34. The method according to claim 31 wherein the controlling of the formation of the fibre layer further comprises the steps of:

receiving of the first substrate layer, the fibre layer and the second substrate layer using a pair of rollers;

25 controlling a pressure applied to the first substrate layer, the fibre layer and the second substrate layer by the pair of rollers; and

controlling a temperature applied to the first substrate layer, the fibre layer and the second substrate layer by the pair of rollers.

35. The method according to claim 31 further comprising the steps of:

30 conveying the layers of the first substrate, the fibre layer and the second substrate towards a separation mechanism; and

separating the layers of the first substrate, the fibre layer and the second substrate into separated layers.

35 36. The method according to claim 35 wherein the separating of the layers further comprises the steps of:

collecting the separated first substrate layer using a first collection roller;

collecting the separated second substrate layer using a second collection roller; and

collecting the separated fibre layer using a fibre collection roller.

5 37. The method according to claim 35 further comprising the steps of:

stopping the first spinning element from producing charged streams after a first period;

removing a lid from a top surface of the collection unit revealing a first hole wherein the collection unit further comprises a container for containing a second solution; and

10 receiving the first spinning element in the first hole.

38. The method according to claim 37 further comprising the steps of:

pumping the second solution from the container to a second solution tank;

15 and

pumping the second solution from the second solution tank to the container through the first spinning element.

39. The method according to claim 23 further comprising the steps of:

20 producing a second charged stream from a first solution using a second spinning element; and

supplying the electrically charged air molecules from a third inlet vent positioned adjacent the second spinning element, whereby the electrically charged air molecules direct the first and second charged streams towards the collection unit.

25

40. The method according to claim 39 wherein the electrically charged air molecules and the first and second charged streams have the same polarity.

41. The method according to claim 39 further comprising:

30 supplying the electrically charged air molecules from a fourth inlet vent positioned adjacent the second spinning element such that the electrically charged air molecules from the first, third and fourth inlet vents form electrically charged air molecule channels for directing the first and second charged streams towards the collection unit.