Melt Blown Process

Related terms:

Extruders, Viscosity, Nonwovens, Resin, Air Velocity, Filament Diameter, Nonwoven Fabric, Spinneret, Spinning Process

View all Topics

Developments in manufacturing techniques for technical nonwovens

H.-G. Geus, in Advances in Technical Nonwovens, 2016

5.3 Melt blown

The melt blown process is a nonwoven manufacturing system involving direct conversion of a polymer into continuous filaments, integrated with the conversion of the filaments into a random laid nonwoven fabric. First developments in this field of technology in the industrial area started around 1945. The general process description is similar to the spunlaid process, but in detail, both types of processes are quite different. Using the melt blown technology, the spun filaments are accelerated by means of hot, fast-flowing air that is directly blown onto a moving substrate, creating a self-bonded web. Figs 5.5–5.8 show principles and sketches of the different melt blown technologies. The hot air temperature is close to the used melt temperature. The achieved filament diameter is one magnitude lower compared to the spunlaid process, 1–5 μm. The calculated filament speed out of throughput and measured filament diameter is resulting in filament speed higher than sonic speed. Since the used air geometries are not suitable to create supersonic speed, the air speed cannot the single source of forces for the downsizing of the filaments.

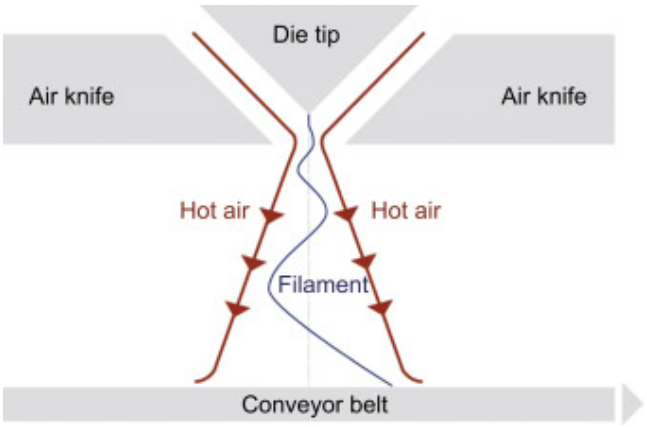

Figure 5.5. Exxon type die.

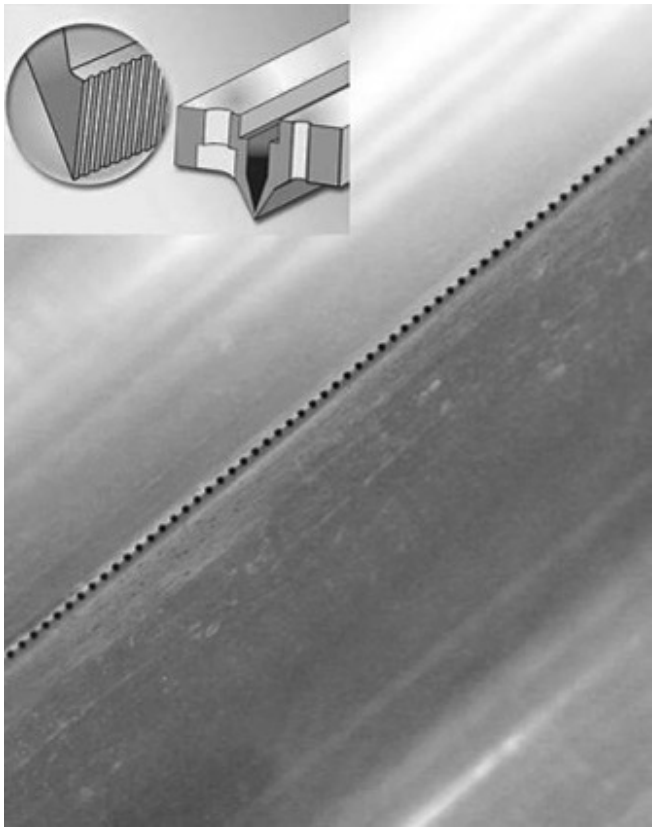
Figure 5.6. Exxon type die – bottom view on spinneret.

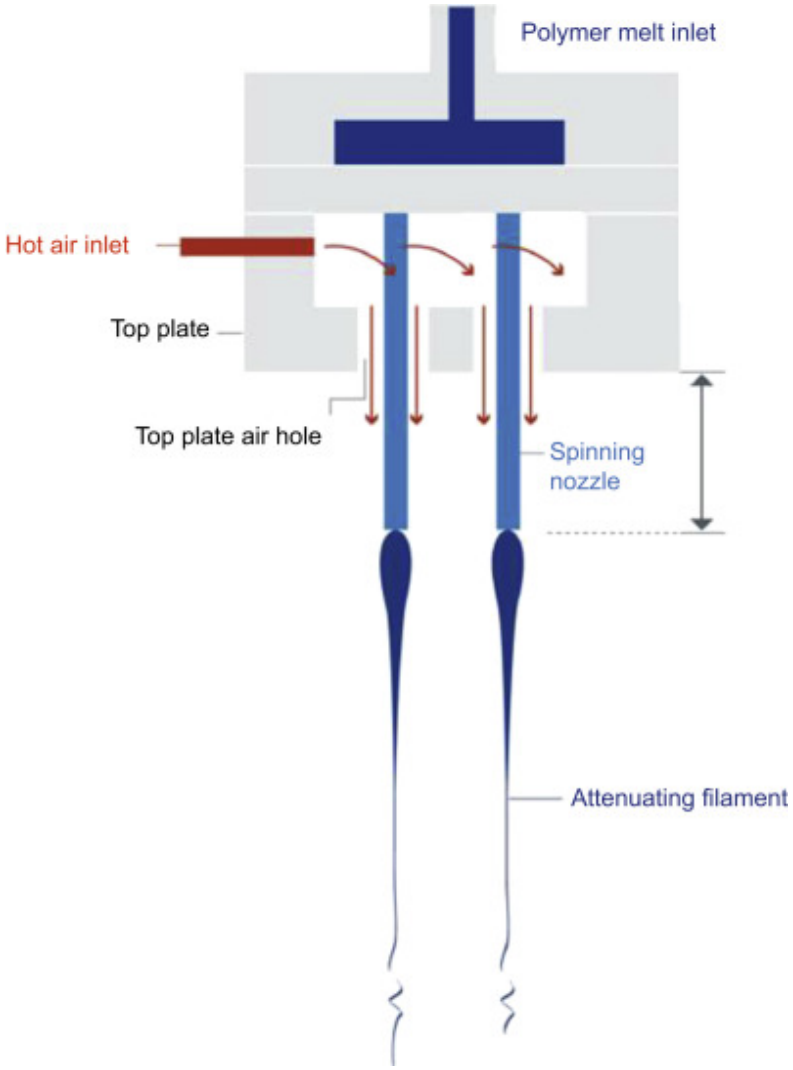

Figure 5.7. Multirow die – US 20090258099.

Figure 5.8. Multirow type die – bottom view on spinneret.

The addition of the forces out of the air speed for the downsizing of the filaments and out of drag forces created within the free air jet is typical for the melt blown process. This effect of combined forces results in a variation of filament diameters along the filaments, so the measured filament diameter distribution is relatively broad. Melt blown fabrics are mainly used for their barrier, filtration and their absorption properties.

> Read full chapter

Technologies for the manufacture of synthetic polymer fibers

J. Hagewood, in Advances in Filament Yarn Spinning of Textiles and Polymers, 2014

3.8 Melt blown processes

The melt blown process (Fig. 3.7) is a one-step process that converts polymer resin into low diameter fiber nonwoven web or tow (Andreas Desch, February 2011). The melt blown process, and its variants, is the only large-scale commercial process that is presently being used to directly produce melt spun fibers with diameters in the submicron range without splitting or chemically dissolving away polymer. It is a nonwovens operation that directly creates fabrics of various widths and thicknesses on large rolls. The products are mainly used in filtration applications, barrier fabrics, oil absorption mats, and battery separators. It is a rapidly growing business segment due to a large increase in the demand for better filtration and membrane medium. The major polymers used in the process are low molecular weight olefins.

3.7. Schematic of the melt blowing process.

The key to the melt blowing process is the spin head. The basic principle is the extrusion of low viscosity polymer melt through a single row of very fine holes placed

close together in the order of 1000–4000 holes per m. These holes are usually drilled or made by fusing together two plates that contain etched channels. High velocity hot air is blown at the exit of the holes from both sides of the row of holes at an angle. This air keeps the molten polymer hot and attenuates the molten polymer into a fine fiber. At the same time a flutter is developed in the air stream that causes the fibers to flap rapidly back and forth as they are cooled by ambient air becoming entrained in the process. Finally the fibers are collected on a screen belt or drum.

The fibers produced by this method are generally very weak with low tenacity and modulus. One reason is that low molecular weight (low viscosity) polymer is required to make the process work well. The other factor is that the hot air keeps the polymer in the melt state as it is being attenuated, which is necessary because of the rapid acceleration of the polymer as it exits the spin hole. This results in low axial molecular orientation in the fiber as it is being formed.

There are several issues that influence the melt blown process which are different from other major fiber spinning processes. The first is the design of the extruder screw which is commonly manufactured specifically for the low densities and low viscosities associated with the polymers used in the process. The polymer must also be filtered to a greater level than required in most other fiber spinning processes. Hot compressed air controlled to an exacting temperature must be provided to the process and the angle of insertion and volume (air gap) of the air must be controlled precisely over the length of the spin head. The use of a single row of holes greatly restricts the fiber mass output of the process per meter of web width. This results in production and cost issues. Several attempts with limited results have been made to design heads that solve this issue and still produce low diameter filaments.

> Read full chapter

Processes for Nonwoven Filter Media

Irwin M. Hutten, in Handbook of Nonwoven Filter Media (Second Edition), 2016

5.2.2 Melt-blown webs

A schematic of the melt-blown process is diagrammed in Figure 5.26 below. The line as diagrammed is blowing the fibers in a horizontal path to the collector. Commercial lines with vertical flow are also in operation.

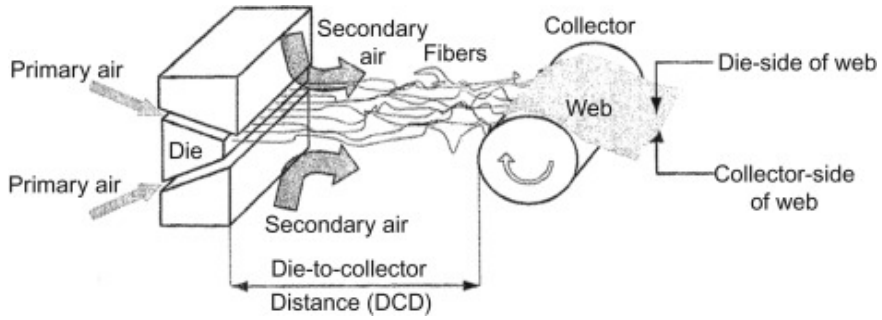

Figure 5.26. The Melt-blowing Process[5].Source: Reproduced with permission of Dr. Randall R. Bresee, (213), University of Tennessee, Knoxville, Tennessee USA.

The key difference between the spunbonded process and melt-blowing is in the die assembly. In the melt-blown process hot air converges with the fiber as it emerges from the die, whereas in the spunbond process the hot air flow is at a cross flow to the emerging fiber. The converging flow of the melt-blown process, diagrammed in Figure 5.27, serves to attenuate and draw the fibers so that the resulting web is composed of finer fibers than the fibers of spunbonded webs. The melt-blown web is softer, bulkier, and weaker. It has a smaller pore size and provides for better filtration efficiency. In most filter applications the medium has to be supported by another web, or used as part of a composite structure.

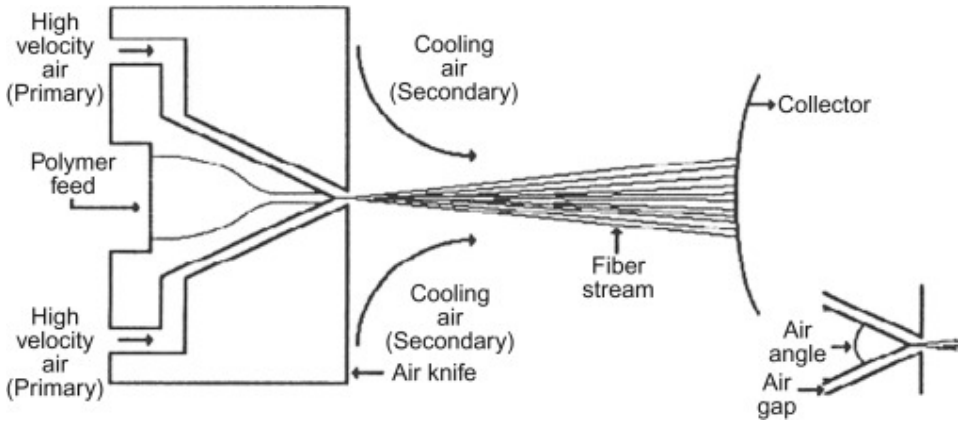

Figure 5.27. Airflows in the Melt-Blown Process.Source: Reproduced by permission of TAPPI Press Atlanta, Georgia USA ((25) p. 183).

The collage of Figure 5.28 is a photo display of the 6-inch pilot melt blowing line at the University of Tennessee Nonwoven Research Laboratory (UTNRL), Knoxville, Tennessee, USA. The process starts with polymer in the form of pallets, granules, powder that is poured into the hopper of Figure 5.28A. From the hopper the polymer gravity drops into the feed throat of the extruder. Inside the extruder is a rotating screw shaft that forces the polymer through three heating zones that melts the polymer. The extruder is shown in Figure 5.28B. The operation of the extruder is similar to the one diagrammed in the schematic of Figure 5.22 above. In the case of the UTNRL pilot machine, the extruder provides sufficient pressure to force the molten polymer flow through the screen, through the die assembly and as fiber unto the collector. The screen changer is shown at the end of the extruder in Figure 5.28C.

From the screen changer the polymer feeds into the back of the 6-inch die assembly, also shown in Figure 5.28C. The screens serve to separate solid contaminants and unmelted chunks from the molten polymer. There are two screens, so that when one becomes filled, it can hydraulically be removed from the polymer flow stream and the other one inserted in place.

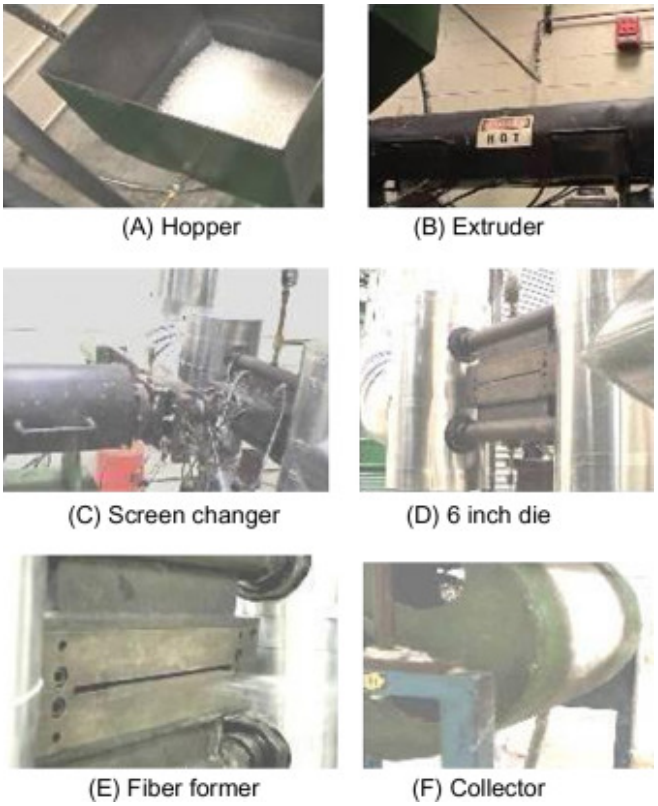

Figure 5.28. 6-Inch Meltblown Line at UTNRL.Source: Reproduced by permission of University of Tennessee Nonwovens Research Laboratory, University of Tennessee, Knoxville, Tennessee USA.

The distributor to the die assembly is a parabolic coat hanger type similar to the one used in the spunbond line discussed above. The parabolic shape is evident in Figure 5.29, a photograph of the coat hanger taken during line disassembly for cleaning. Polymer enters from the feed pipe, at the top of the device, and exits through the melt-blown die at the bottom. The coat hanger configuration provides for even polymer distribution across the die.

Figure 5.28D shows the front of the die assembly where the fibers emerge. On both sides of the die, insulated piping can be seen. The insulated piping feeds hot air into two manifolds which are the pipe-like structures seen above and below the die opening. The manifolds regulate the high velocity streams of hot air that converge with the forming fibers as shown in Figure 5.24 above. Typical hot air temperatures are 215 °C to 340 °C. The air velocities through the air channels above and below the polymer feed die openings range from 0.5–0.8 times the speed of sound.

There are two types of die nosepieces: capillary type and drilled hole type. These are pictured in Figure 5.30 above. Capillary openings are actually slots that are milled into both sides of the flat mating surfaces that form the die nosepiece. This is shown in Figure 5.30A above. Figure 5.30B above illustrates the drilled hole types. The die holes are either mechanically drilled or drilled by electrical discharge machinery.

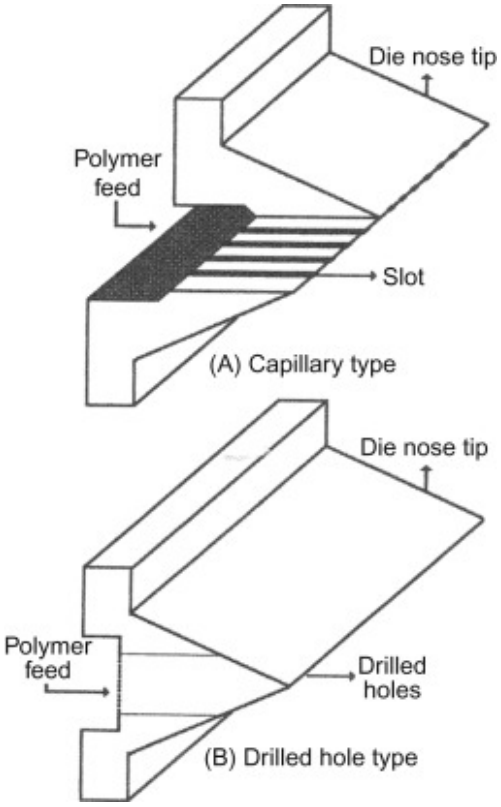

Figure 5.30. Schematic of Die Nosepieces for Melt-Blown Lines.Source: Reproduced by permission of TAPPI Press Atlanta, Georgia USA (25), p. 183).

During processing, the entire die assembly is heated to 215 °C to 340 °C in order to produce uniform defect-free webs. Figure 5.28E shows the newly formed fiber emerging from the die on its way to the collector (Figure 5.28F). The fiber emerging from the die is traveling from left to tight whereas the collector is pictured from the other side of the machine so that the fiber approaching it in Figure 5.28F is coming from the right. The metal drum collector in Figure 5.28F, is rotating counterclockwise.

The melt-blown process is a major process for producing nonwoven filter media. The major development areas for the process are webs with finer fibers for greater filtration efficiency and webs containing bicomponent and multicomponent fibers. With respect to the latter, Hills Inc. of West Melbourne, Florida has developed proprietary melt-blowing technology to produce fibers with the following cross sections:

- Homopolymer
- Side by side

- Sheath/core
- Pie segments
- Islands in a sea

A detailed discussion of bicomponent and multicomponent fibers is presented in Chapter 4, Section 4.3.5.6Chapter 4Section 4.3.5.6.

> Read full chapter

Advances in fabric structures for wound care

Erdem Ramazan, in Advanced Textiles for Wound Care (Second Edition), 2019

18.4.5.5 Melt-blown web forming

It is a single-step process that transforms polymer as a raw material into the web structure. The basic illustration of the melt-blown process is presented in Fig. 18.13. Firstly, polymer is melted in an extruder, and then it passes through the die holes in the spinneret and goes into the high-velocity hot airstream. Web structure is established when fibre entanglement occurs. At the end, blown ultrafine fibres are collected on a rotating drum or a forming belt with a vacuum underneath to generate a nonwoven web. Polymer properties, air velocity, equipment variables and the degree of fibre entanglement significantly influence the characteristics of the final web structure. In general, in this system fibres with diameter of 1–10 μm can be produced, and any thermoplastic polymer, including biodegradable ones, can be processed [16,37].

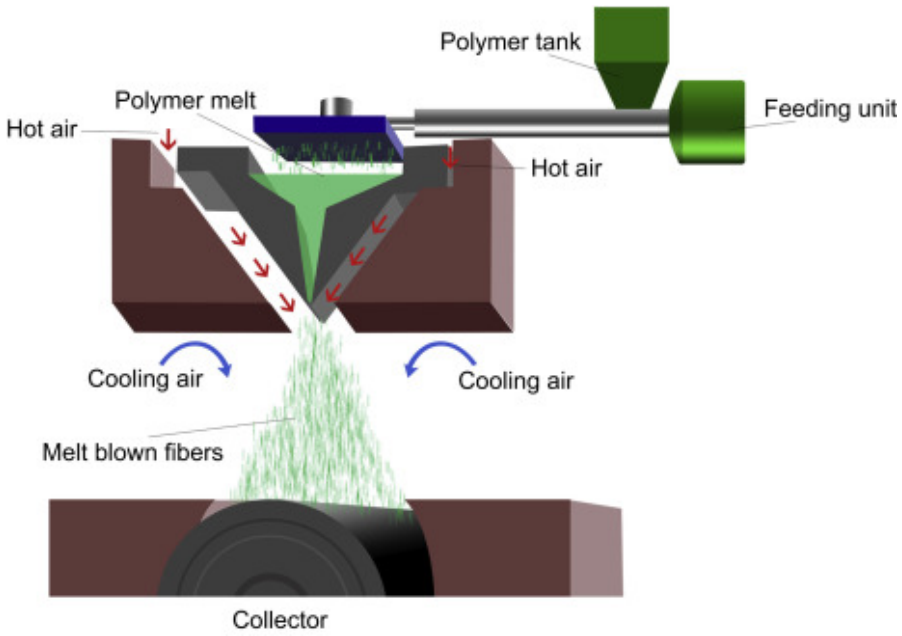

Figure 18.13. Melt-blown process.

> Read full chapter

Raw Materials for Nonwoven Filter Media

Irwin M. Hutten, in Handbook of Nonwoven Filter Media (Second Edition), 2016

4.3.5.4.1 Glass fibers

Glass fibers are formed to a broad range of fiber diameters. They are classified by diameter and by chemical composition. They can be produced as microfibers and as chopped strand. The process is a melt-blown process related to the melt-blown process for producing polymer webs (see Chapter 5, Section 5.2.2Chapter 5Section 5.2.2). Two primary processes for producing glass microfibers are rotary attenuation and flame attenuation. Figure 4.24, provided by Lauscha Fiber International, Lauscha, Germany, is a picture of glass microfiber produced by both of these processes. In both processes, the fibers are flame attenuated to control their diameters. From these, Scheffel (167) describes four variations as follows:

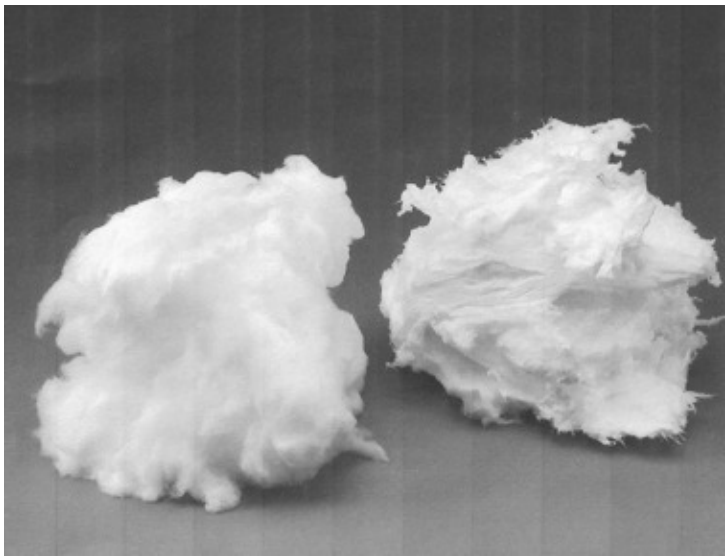

Figure 4.24. Rotary and Flame-Attenuated Fibers.Reproduced by Permission of Lauscha Fiber International, Lauscha, Germany.

a. Rotary Process—The rotary process is diagrammed in Figure 4.25. Molten glass is charged into a rotating basket-like device having a large number of holes as centrifugal openings. Because of the centrifugal forces arising due to the rotation, the glass melt flows to the circumferential wall and is driven out through the openings as primary monofils. A hot gas stream transverse to the direction of the monofilaments draws them to fine glass fibers.Figure 4.25. Rotary Process.Reproduced with Permission of the American Filtration and Separation Society, Nashville, Tennessee, USA (167), p. 188.
b. CAT process—The controlled attenuation technology (CAT) process represents a modified rotary technology with less and thinner monofils and a significantly higher gas stream (Figure 4.26).Figure 4.26. CAT Process.Reproduced with Permission of the American Filtration and Separation Society, Nashville, Tennessee, USA (167). p. 189.
c. Flame attenuation process—This process is characterized by primary monofils with diameters of 25 to 38 µm that are drawn from a platinum bushing and then fiberized by a highly accelerated hot gas stream (Figure 4.27).Figure 4.27. Flame Attenuation Process.Reproduced with Permission of the American Filtration and Separation Society, Nashville, Tennessee, USA Society (167), p. 190).
d. Duplex process—The starting materials are glass rods from which primary monofils with diameters of 0.3 to 1.0 mm are continuously drawn mechanically and these are fiberized in a highly accelerated gas stream of high temperature (Figure 4.28).Figure 4.28. Duplex Process.Reproduced with Permission of the American Filtration and Separation Society, Nashville, Tennessee, USA (167), p. 191.

Several glass compositions are available for the production of glass microfibers. Lauscha Fiber International (168) lists three compositions (A, B, and E) in Table 4.32. According to Lauscha, A-Glass is an alkali silicate glass composition developed to reduce possible contamination from boron outgassing in critical clean room filtration applications. This is particularly important in clean room filters in the electronic industry, where even a few molecules of boron contamination can destroy a large batch on high purity electronic components. B-Glass is a borosilicate glass chemistry designed for broad use in a full range of applications including air, gas, and liquid filtration. E-Glass microfiber is unique within the industry. Lauscha's technology enables fiberization of electrical grade E-Glass to submicron levels with no shot and no organic contamination. E-Glass microfiber has specific applications in advanced analytical filtration and diagnosis. It is designated as an electrical grade glass because of its relatively high electric conductivity.

Table 4.32. Chemical Composition Lauscha Glass Microfibers

Glass composition	A-Glass (%)	B-Glass (%)	E-Glass (%)
SiO_2	69.0–71.0	55.0–60.0	50.0–56.0
Al_2O_3	2.5–4.0	4.0–7.0	13.0–16.0
B_2O_3[a]	<0.09[a]	8.0–11.5	5.8–10.0
Na_2O	10.5–12.0	9.5–13.5	<0.60
K_2O	4.5–6.0	1.8–4.0	<0.40
CaO	5.0–7.0	1.0–5.0	15.0–24.0
MgO	2.0–4.0	<2.0	<5.5
Fe_2O_3	<0.20	<0.25	<0.50
ZnO	<2.0	2.0–5.0	<0.02
BaO	–	3.0–6.0	<0.03
F_2	<1.0	<1.0	<1.0
TiO_2	–	–	<1.0

a B_2O_3 contains 31.1% boron by weight. It follows that the maximum allowable boron content in A-Glass is 0.028%.

Reproduced by Permission of Lauscha Fiber International, Lauscha, Germany (168).

Johns Manville lists two: 475 chemical composition for their 100 series of glass microfiber and 253 low boron chemical composition for their 200 series. These compositions are listed in Table 4.33.

Table 4.33. Chemical Composition Johns Manville Glass Microfibers

Glass composition	475 chemical composition for 100 series	253 chemical composition for 200 series
SiO_2	58.3	65.5
Al_2O_3	5.8	3.1
B_2O_3	11.3	5.3

Na_2O	10.1	16.0
K_2O	2.9	0.7
CaO	1.8	5.9
MgO	0.3	3.0
ZnO	4.0	–
BaO	5.0	0.01

Reproduced by Permission of Johns Manville, Denver, Colorado, USA.

Fiber diameter determines the filtration efficiency of filter media made from glass microfibers; the finer the diameter, the more efficient will be the medium. It is common practice to grade glass microfibers with a numbering system: the lower the number, the smaller the fiber diameter. Lauscha uses a system that identifies the glass composition A, B, C, or E, and uses a two-digit number from 00 to 50 for the fiber diameter code. 00 is the smallest diameter available and 50 is the largest. Their grade numbering system (see Table 4.34) also includes a letter designation to identify the fiberization technology (F, flame attenuation; Fi, high speed F-technology; and R, rotary attenuation). For example, Grade B-06-F would be a glass microfiber composed of the B-Glass composition in Table 4.34, having a fiber diameter code of 06, and produced by flame attenuation (F) technology. Table 4.35 lists several of the Lauscha grades along with their fiber diameters and specific surface areas (SSA). Figure 4.29 relates Lauscha grades and SSA to handsheet pressure drop. It is apparent from the Lauscha data that the finer the fiber diameter, the larger is the SSA and the larger the SSA, the more resistant will be the medium to flow.

Table 4.34. Lauscha Product Designation System

Reproduced by Permission of Lauscha Fiber International, Lauscha, Germany ((169), p. 1).

Table 4.35. Lauscha Glass Microfiber for Air and Liquid Filtration

Microfiber chemistry	Grade	Nominal diameter µm	Nominal specific surface area m^2/gm	Fiberization technology
B-Glass	B-X9 Fa	0.26	6.20	Flame Attenuated
B-00-Fa	0.33	4.80		Flame Attenuated
B-02-F	0.46	3.50		Flame Attenuated
B-04-F	0.53	3.00		Flame Attenuated
B-06-F	0.65	2.47		Flame Attenuated
B-08-F	0.80	2.00		Flame Attenuated
B-10-F	1.00	1.60		Flame Attenuated
B-15-F	1.48	1.08		Flame Attenuated
B-26-R	2.44	0.66		Rotary
B-39-R	3.20	0.50		Rotary

B-50-R	4.10		0.42		Rotary
B-56-R	5.00		0.35		Rotary
A-Glass	A-04-F	0.53		3.00	Flame Attenuated
A-06-F	0.65		2.47		Flame Attenuated
A-26-F	2.44		0.66		Flame Attenuated
E-Glass	E-04-Fa	0.56		2.88	Flame Attenuated
E-06-F	0.65		2.47		Flame Attenuated
E-08-F	0.80		2.00		Flame Attenuated

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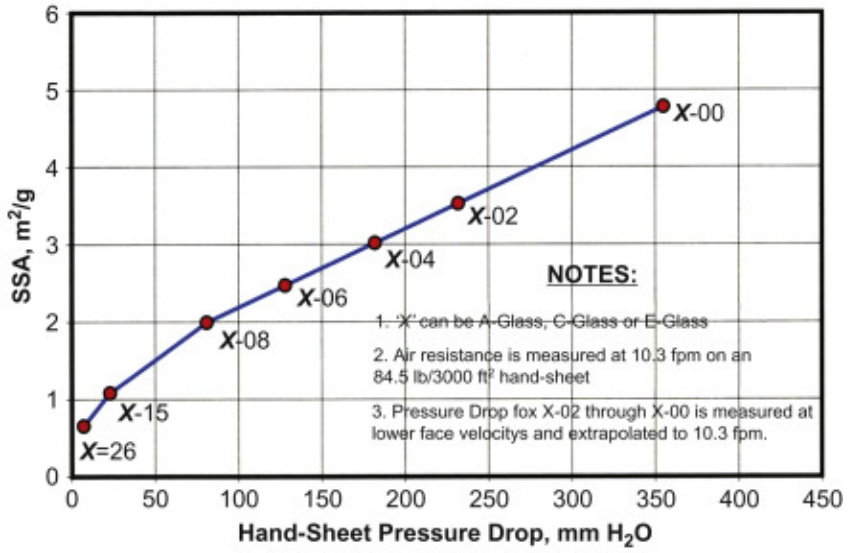

Figure 4.29. Lauscha Relationship Between Fiber Grade, Pressure Drop, and Specific Surface Area (SSA).[6]Reproduced by Permission of Lauscha Fiber International, Lauscha, Germany.

The Johns Manville system uses a digital number series: 90 and up for the 475 glass composition and 200, and up for the 253 glass composition. There is also a CX grade for the 5.5 µm diameter. Figure 4.30 plots the Johns Manville code versus fiber diameter.

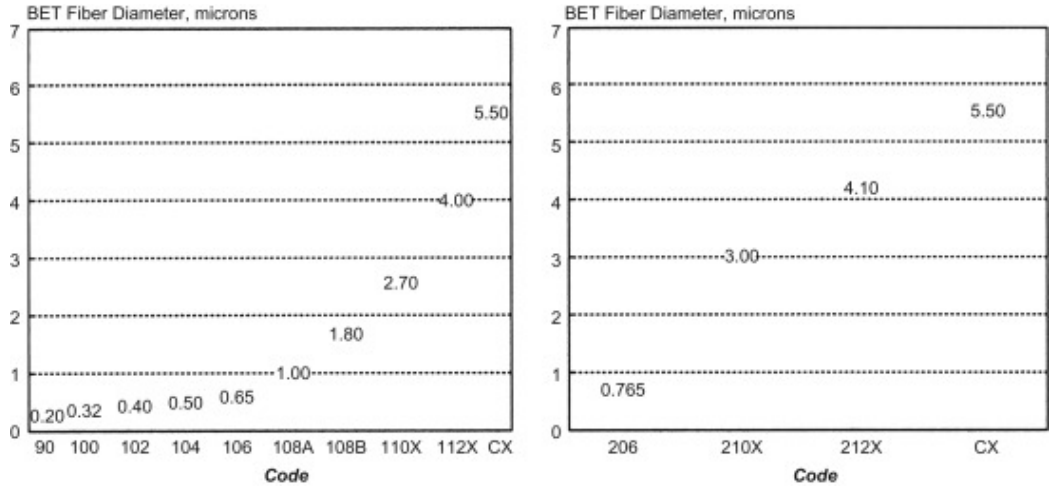

Figure 4.30. Johns Manville Glass Microfiber Codes Versus Fiber Diameter.Reproduced by Permission of Johns Manville, Denver, Colorado, USA.

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Nonwoven fabric filters

N. Mao, in Advances in Technical Nonwovens, 2016

10.2.5 Spunbond and melt blown nonwoven fabrics

Spunbond and melt blown nonwoven webs are formed from the collection of continuous filaments produced by melt extrusion processes on a conveyor belt.[51] There are distinct differences in the structure and properties of spunbond and melt blown webs, which result from the difference between the two processes, that the melt blown process involves the attenuation of the filaments using high-velocity hot air streams that impinge on the extruded filaments as they are emerged from the extrusion nozzles to obtain much finer filaments.[52] Melt blown fabrics consist of smaller diameter filaments, including submicron filaments, and have superior filtration properties, while conventional spunbond fabrics contain coarser fibres and have much greater tensile strength and smaller pressure drop. There is also a large variation in the diameter of filaments in melt blown webs as compared to spunbond. In practice, melt blown–spunbond multilayer fabrics (eg, spunbond-melt-blown (SM), spunbond-meltblown-spunbond (SMS)) frequently used in filtration applications. Bicomponent continuous filaments that consist of more than one polymer type arranged in different configurations within the filament cross section (eg, side-by-side, core-sheath, segmented pie, and islands in the sea, etc.) are utilized to produce nonwoven fabrics containing microfibres and submicrofibres by splitting or fibrillating the filaments in the web after it has been extruded.[50] Melt blown fabrics are frequently combined with nanofiber webs to achieve greater filtration efficiency.[53]

Spunbond and melt blown fabric filters, being made from continuous filaments, have the advantage of flexibility to bond with other types of webs, resisting shedding, relatively higher mechanical strength, and are stable and resilient. They also have the advantage of forming functional fibres (eg, antibacterial) and achieving permanent treatment (eg, flame retardant) in fibre extrusion stage. But these types of filters usually have neither the flexibility of having blended different types of fibres nor mixed fibre diameters.

> Read full chapter

Textile materials and structures for topical management of wounds

B.S. Gupta, J.V. Edwards, in Advanced Textiles for Wound Care (Second Edition), 2019

3.12.6.10 Advanced composites from combination of technologies

Attractive composites can be made by a combination of air-laid and spunlace processes. One example is infusing pulp by air-laying onto a regular cotton or rayon web during hydroentangling. Such a product has similar or superior absorbency of 100% cotton or rayon fabric but at a fraction of the cost. A typical blend ratio for pulp and fibre will be 50/50. Such a structure can be used as the absorbent layer in a dressing.

Another structure that has received great emphasis during the past two decades is one that combines spun-bond and melt-blown processes in producing a composite fabric. Examples of these are the spun-bond (SB)/melt-blown (MB), known as SM, and the SB/MB/SB or SMS composites. Often two layers of melt-blown are sandwiched between two spun-bond layers to lead to SMMS. The production and properties of these are particularly enhanced by the use of polypropylene/polyethylene bicomponent materials in the preparation of MB webs [149,150]. The spun-bond fabric, combined with ultra-lightweight melt-blown fabric, is suited for use as facing for absorbent products (Fig. 3.23).

Figure 3.23. Micrograph of a polypropylene SMMS fabric [150].

Most interesting of the composite structures, however, that can lend to direct use as dressings, are the cellulose-centred nonwovens that are capable of being produced

on an integrated line [129,151]. These are laminates that have cotton, or another cellulosic fibre web, sandwiched as a core between two layers of melt-blown and/or spun-bond webs, with the size and the characteristics of each of the three adjusted to suit the application. For developing such products, the absorbent material used could be cotton or rayon of regular length, fed from a pre-formed roll, or pulp of short length, deposited directly from an air-laying system on the site in coordination with the formation of the spun-bond/melt-blown webs (Fig. 3.24).

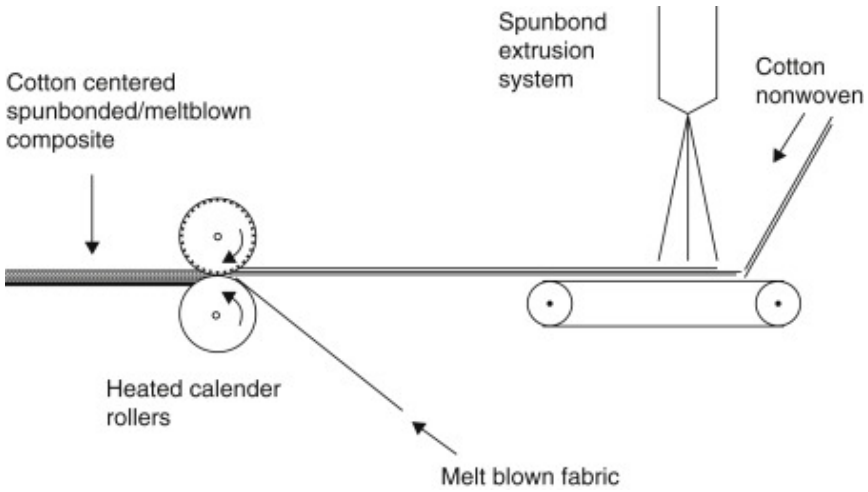

Figure 3.24. Preparation of cotton-centred composite with spun-bond and melt-blown webs forming the outer surfaces.

> Read full chapter

Introduction to Nonwoven Filter Media

Irwin M. Hutten, in Handbook of Nonwoven Filter Media (Second Edition), 2016

1.7.1.2 Polymer sourced

1.7.1.2.1 Melt spun

There are two major melt spun processes that produce polymer sourced nonwoven webs: spunbond and melt-blown. Both follow the general process flow diagram of Figure 1.15. Polymer in the form of powder granules or pellets is fed from a hopper into an extrusion chamber where the polymer is heated to a molten state. The molten polymer is then extruded through a gear pump and screen (to remove unmelted contaminants or chunks) and fed into a die block or spin pack. The polymer is then forced through a spinnerette block containing thousands of micro-diameter holes. The fibers, so formed, are attenuated, cooled, and randomized on their way to form a nonwoven web structure on the collector belt. The significant difference between

the processes is the manner in which air is introduced to cool and/or attenuate the fibers as they emerge from the spinnerette. This is illustrated in Figure 1.16. Note the quenching air flow for the spunbond process is horizontal to the vertical direction of the fibers and intended to cool the fibers as they emerge from the spinnerette. On the other hand, the melt-blown hot air flow is in the diagonal direction and merges with the fibers as they merge with the hot fibers from the spinnerette. The merging action of the hot air flow attenuates the fiber much more than is done in the spunbond process. As a result, the melt-blown fibers are much finer than the spunbond fibers, and the melt-blown fleece formed is softer and weaker.

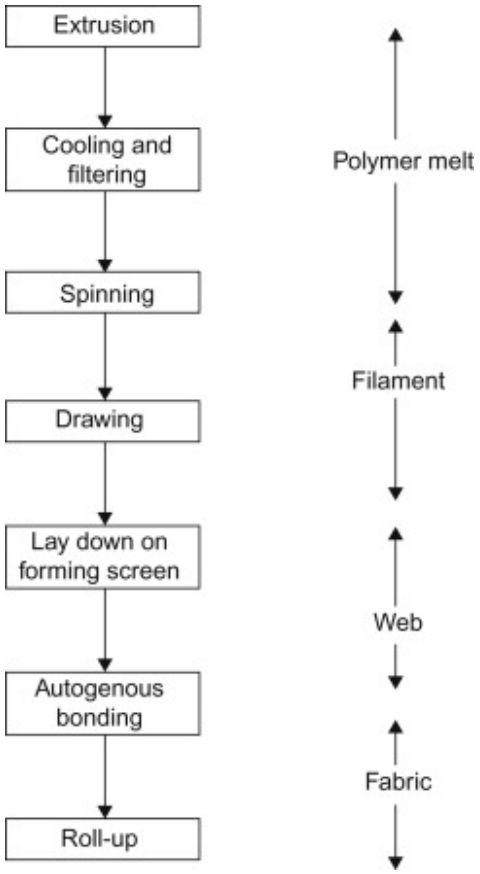

Figure 1.15. Generic of the Meltspun Processes.Reproduced by Permission of TAPPI, Atlanta, Georgia USA.

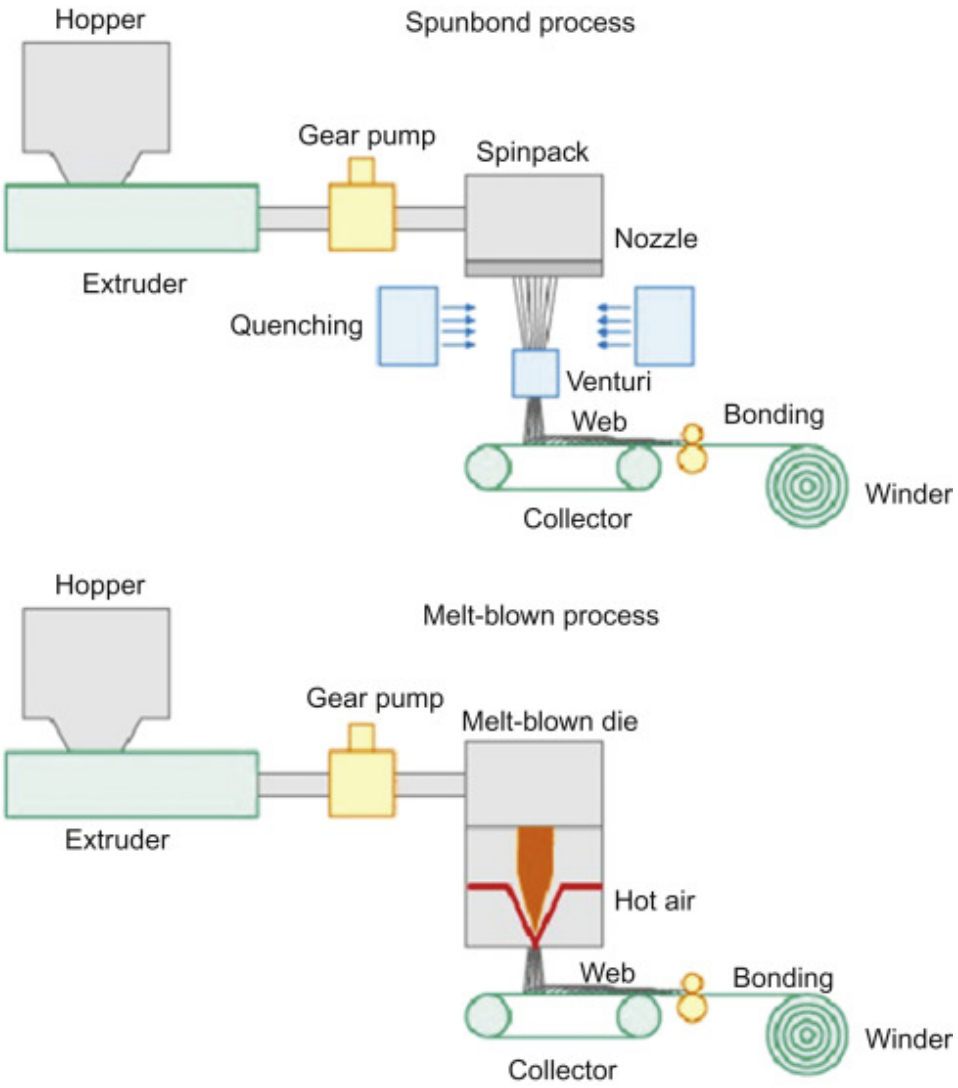

Figure 1.16. Comparison of Meltspun Processes.

1.7.1.2.1.1 Spunbonded

There are several manufacturers of spunbonded systems. The Reicofil system developed by Reifenhauser GmbH of Germany as described by Malkan and Wadsworth (25) is discussed in detail in Chapter 5, Section 5.2.1. Other manufacturers of spunbond systems are Kohle and Mineraloltechnik GmbH of Germany (Docan System) and Carl Freudenberg Co. of Germany (Lutravil System).

Polymers generally used in the spunbond process are polyester (Reemay®), nylon (Cerex®), and polypropylene (Typar® and Tekton®). Polyurethane and rayon have also been successfully spun into spunbonded webs. More recently Freudenberg Filtration Technologies, Wenheim, Germany has introduced Lutrador® ECO, a spunbonded web produced from exclusively postconsumer recycled (PCR) plastic materials. The trade names mentioned are those that were identified with the materials when originally introduced. Currently, there are at least 80 different trade names for spunbonded filter media.

1.7.1.2.1.2 Melt-blown

Melt-blown webs are formed directly from a molten resin. The process is similar to spunbonded webs in that thermoplastic polymers are extruded through a spinning die, to form filaments. It is different than spunbonded webs in that high velocity, heated air, injected near the die tips, converges with the filaments to attenuate them to very fine diameters. The attenuated filaments are quenched with cool air and collected on a moving collector screen. The attenuated filaments are generally 1–4 μm in diameter and form a very uniform web at low grammage. Figure 1.17 is the diagram of the typical melt-blown process.

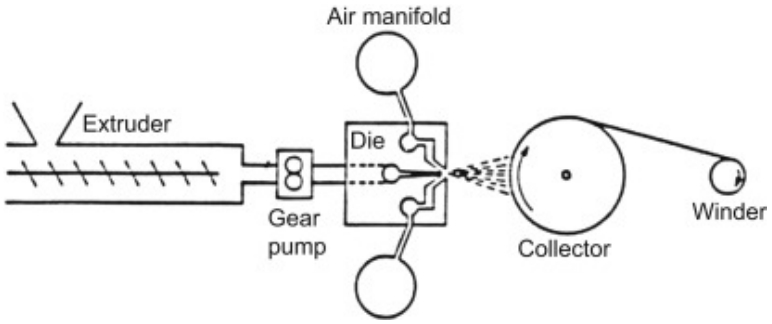

Figure 1.17. Schematic of Melt-Blown Process.Reproduced by permission of TAPPI, Atlanta, Georgia USA.

Polypropylene and poly butyl terephthalate are the most frequently used polymers used for producing melt-blown webs.

The principal difference between melt-blown webs and spunbonded webs is that the melt-blown process produces a web composed of finer filaments. Melt-blown webs are generally softer and weaker than spunbonded webs. Melt-blown webs are often used in a composite or laminated form combined with a supporting web or material to provide strength and stability. Butler estimated (5) that two thirds of melt-blown consumption is used in composite form. The largest volume composite structures are spunbonded/melt-blown structures. More will be said about composite structures in Section 1.7.3. The fine fiber structure of melt-blown webs makes them candidates for high efficiency filter media, both in liquid and in air filtration applications.

1.7.1.2.2 Flash spinning

In contrast to meltspun products, flash spinning forms nonwoven webs from a solvent solution of a polymer. The solvent solution of polymer is extruded through the spinnerette and the solvent quickly evaporates causing the filaments to form a highly fibrillated form before they are deposited on a screen. The web is thermally bonded with a calender roll to form a strong fabric. It is by this process that the high density polyethylene fabric known as Tyvek®[8] is produced. Tyvek® in itself is

generally too dense to be used as a filter medium, however a variation to this is a series of filter grades, marketed by DuPont, known as SoloFlo® (see Section 3.4).

1.7.1.2.3 Nanofiber spinning processes

There are two known commercial types of processes for spinning webs made of nanofiber: electospun webs and centrifugal spun webs.

1.7.1.2.3.1 Electroformed webs

In 1934, Anton Formals (26) was the first inventor to patent an electrospinning phenomenon. Electrospinning is a process that produces nanofiber webs by applying a high-voltage charge to a polymer solution or melt and using the charge to draw the solution from the source to a grounded collector. The source may be a needle, a nozzle, a spinnerette, or a rotating surface.

Voltages range from 5 to 30 kV, sufficient to overcome the surface tension forces of the polymer. The free surface of the charged polymer produces very fine jets of liquid that are rapidly drawn to the grounded collector. The effect causes substantial drawing of the rapidly solidifying fibers as they approach the grounded collector. The highly attenuated fibers collect on a moving surface passing over the grounded collector and form an interconnected web of small filaments. The fiber diameters for filtration purposes are in the range of 0.25 µm. The webs are of very fine thickness (on the order of 1 µm or less) and have limited mechanical properties. The moving surface on which they are collected is usually a substrate that will provide strength and stability for subsequent processing. Very often the substrate will be a nonwoven chosen specifically for the filtration application.

Figure 1.18 is a schematic of the laboratory needle process and Figure 1.19 is a SEM image of a nanofiber web produced in this manner.

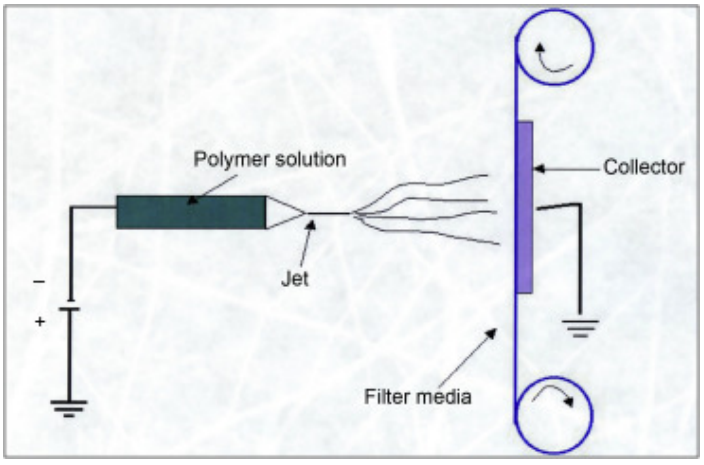

Figure 1.18. Schematic of the Electrospinning Process.Reproduced with permission from Donaldson Company, Inc © Donaldson Company, Inc. All rights reserved.

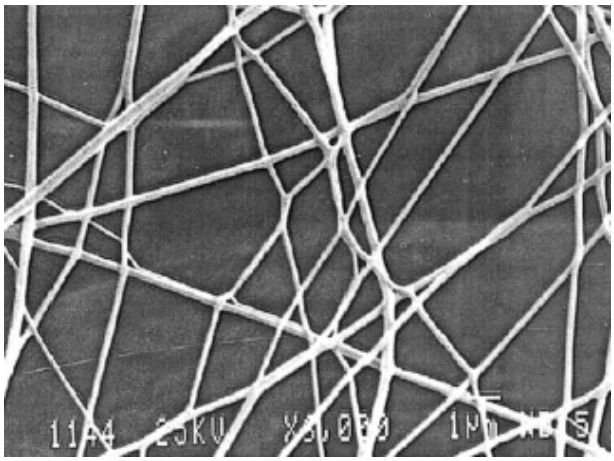

Figure 1.19. Electrospun Nanofiber Web.Reproduced with permission from Donaldson Company, Inc © Donaldson Company, Inc. All rights reserved.

DuPont has patented an electro-blowing process (27) that spins a fiber-forming polymer solution from an electro-charged spinnerette. The spinnerette process appears similar in principle to the melt bond process except that the polymer is solution polymer rather than molten polymer and the force driving the polymer solution through the spinnerette is voltage driven as well as pressure driven. In Chapter 5, Section 5.3.4Chapter 5Section 5.3.4. Figure 1.20 is a schematic of the process (28). Process details are proprietary; however, it appears to be a variation of the melt-blown process in that a high-voltage charge is applied to the spinnertte. Note from Figure 1.20 that the airflows converging around the filament fibers as they emerge from the spinnerette openings, similar to the air flows of the melt-blown spinnerette (see Figure 1.17). The angled air flow around the spinnerette results in a drag motion around the emerging filaments causing them to attenuate. In the electro-blown process, the fiber attenuation is further enhanced by the electric voltage differential between the spinnerette and the collector. The electro-blowing process is further discussed in Chapter 3, Section 3.5.1, and Chapter 5, Section 5.3.4Chapter 3Section 3.5.1Chapter 5Section 5.3.4.

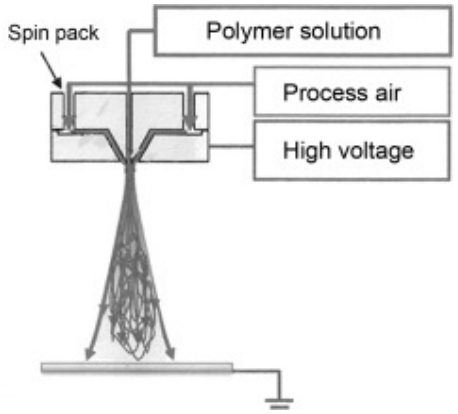

Figure 1.20. DuPont® Electro-Blowing Process (28).Reproduced with permission of DuPont, Wilmington, Delaware USA.

Currently, air filtration applications are the significant markets for electrospun nanofiber webs. This includes engine air intake filters, turbine air filters, pulse filters for dust collection systems, and vacuum bag filters. A good discussion on the air filtration applications is provided by Graham et al. (29). Electrospun nanofiber filter media are also finding niches in liquid filtration. For example, they are a source of nanofiber membranes' use in aqueous microfiltration and ultrafiltration applications (see Chapter 7, Section 7.5Chapter 7Section 7.5).

A more detailed discussion of the various electrospun processes is provided in Section 5.3.

1.7.1.2.3.2 Centrifugal spinning

There are two known processes for centrifugal spinning of a nanofiber web: Forcespinning®[9] by FibeRio® Technology Corporation of Edinburg, Texas, USA and a Melt Spun Nanofiber Process (MSNP) by DuPont®.

The Forcespinning® process is based on a spinnerette orifice nozzle attached to a rotating disk. Figure 1.21 is a photograph of the FibeRio laboratory process. The disk contains molten or solution polymer that is forced out of attached nozzles and then attenuated to nanofiber dimensions. In the laboratory process, of Figure 1.21, the web is deposited on a set of vertical bars structured around the spinning disk. This is the laboratory process. FibeRio markets commercial machine processes that produce webs in a continuous uniform flat-sheet manner. This is further discussed in Chapter 5, Section 5.4.1Chapter 5Section 5.4.1.

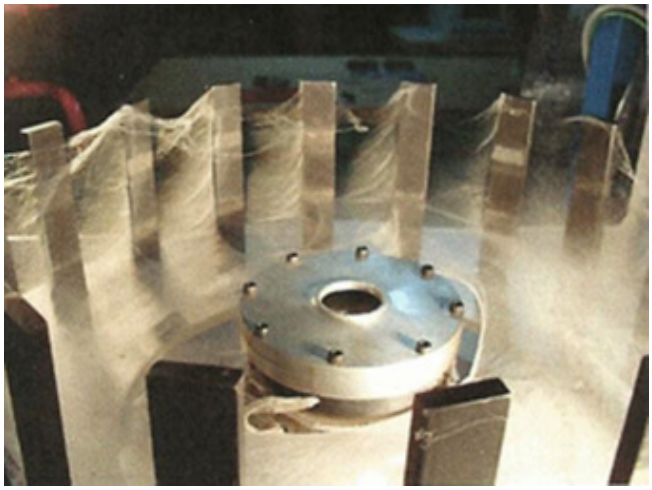

Figure 1.21. FibeRio Forcespinning™ in Progress.Reproduced with permission of FibeRio Technology Corporation, Edinburg, Texas USA.

The DuPont® MSPN process works with melt-based polymers. The centrifugal action of the spinnerette head lays down the fibers in a circle (see Figure 1.22). The gap between circles caused by the advancing collector causes each circle to intersect with the previous circle and with the one after it forms an intersecting set of circular

filaments. This action combined with the action of adjacent spinnerettes creates a nanofiber structure that has all the appearance of a random nonwoven web.

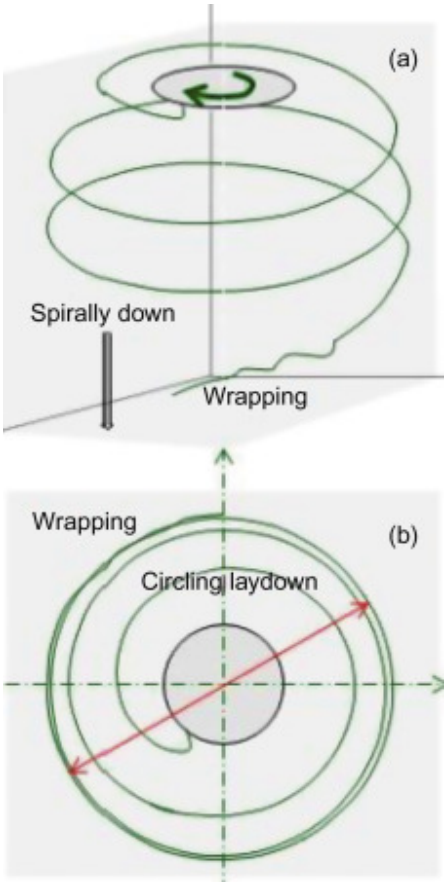

Figure 1.22. Melt Spun Nanofiber Process (MSNP) by DuPont.Reproduced with permission of DuPont, Wilmington, Delaware USA.

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Fiber-based hybrid structures as scaffolds and implants for regenerative medicine

R. Brünler, ... C. Cherif, in Smart Textiles and their Applications, 2016

12.3 Fibers from biopolymers

Theoretically, most materials can be processed into fibers. However, fibers that may be used in textile manufacturing processes must meet certain criteria, namely mechanical strength, elasticity, fiber diameter, fiber length, and yarn count [22]. Due to these reasons, scaffolds made by textile manufacturing techniques are in most cases made of synthetic melt or wet spun polymers (eg, PLA, polyglycolic acid (PGA), PLLA, Polylactide-co-glycolide (PLGA), PCL) [23]. This section gives an

overview on the available fiber formation techniques and the characteristics of the resulting fibers.

12.3.1 Melt spinning

Melt spinning is the standard manufacturing technique for conventional degradable absorbable synthetic biopolymers. Melt-spun biopolymer fibers, especially PLA, PGA, PCL, and their derivatives, are widely used since they have FDA approval and are commercially available. In brief, molten thermoplastic polymers are fed in a constant flow rate into a spinning head, where the polymer is pressed through a spinneret equipped with holes of defined geometry. The resulting continuous filaments are cooled, drawn, and collected. A detailed description of the melt spinning process is given by Freudenberg in Ref. [24].

The melt spinning process is distinguished by defined filament cross-section geometries and a huge variety regarding fineness and filament count. The spinneret may contain a large number of holes enabling a high spinning capacity unmatched by other spinning processes. No solvent is needed in the spinning process ensuring a high purity of the spun polymers. However, ultra-fine fibers may be fabricated by two-component spinning or the melt-blown process. By using a defined ratio of copolymers, fibers with adjustable absorbance kinetics may be produced.

Due to the process characteristics only polymers with high decomposition temperatures and low melt viscosities can be used in melt spinning. Thus, the range of biopolymers is limited due to denaturation or decomposition of those sensitive materials.

12.3.2 Solution spinning

Next to melt spinning, solution spinning is another major fiber fabrication method. Briefly, a polymer solution is fed to a spinneret. The filaments are either spun into a spinning bath where the solvent coagulates (wet spinning) or led through air in which the solvent evaporates (dry spinning). A detailed description of solution spinning is given by Freudenberg [24].

For the fabrication of biomedical fibers, which actively contribute to tissue formation or wound healing, solution spinning is attractive since natural or nature-derived biopolymers that do not form thermally stable melts (eg, polysaccharides, proteins) may be processed into fibers. A lot of effort is put into the development of natural or nature-derived biomaterial fibers with adequate properties for subsequent textile manufacturing, with special focus on regenerated or recombinant silk proteins from silkworms [25,26] or spiders [27], collagen [28,29] and chitosan [30,31]. For the production of natural or nature-derived biomaterial fibers, existing spinning techniques

have to be adapted in order to preserve the microstructure of the biomaterials (ie, benign solvents, moderate process temperatures).

The solvents have to be removed completely to maintain the properties of the spun biopolymers. This requires a full evaporation of all solvents in the drying zone in dry spinning and usually multiple washing baths and a downstream drying unit in wet spinning, which makes solution spinning more complex and more costly than melt spinning.

12.3.3 Electrospinning

Electrospinning (ES) is a technique to produce very fine fibers from polymer solutions or melts by applying electrostatic force. Thanks to its versatility and the easy spinning setup, ES has gained enormous attention in the past 15 years [32]. Especially for applications in the field of regenerative medicine, ES holds great promise since it allows the fabrication of biomimetic support structures.

Electrospun structures offer enormous functional surfaces due to the excellent ratio between surface and volume offered by fibers in the nanoscale. Thus, specific interface properties and cell or tissue responses can be adjusted. A very broad range of materials and material combinations may be processed by ES. Depending on the fiber collection, single fibers, randomly arranged nonwovens, highly aligned fibers, or even nanofiber yarns may be fabricated [33]. The fiber's morphologies and surface topographies may be designed specifically. ES may also be used for the incorporation of drugs by coaxial spinning, solution blending, or surface modification [34,35].

Despite the simple basic setup and its versatility, it has to be considered that the ES process is influenced by numerous interacting parameters [36]. To date, the complex mechanism of fiber formation has not been thoroughly understood. While ES is well suited for producing thin layers or membranes with large surfaces and small pore sizes, the technique is not suitable for producing thicker films due to the long production time resulting from the small fiber diameters.

12.3.4 Other fiber formation techniques

Apart from the above-mentioned fiber formation techniques, biomaterial fibers may be produced by other techniques. Among these, biospinning plays an important role. Biospinning is defined as the process of direct fiber drawing from the spinning glands of various insects such as silkworms and spiders [37]. Biospun fibers, eg, from *Bombyx mori* silkworms, have been traditionally used as suture material [38].

Microfluidic spinning is another promising technique. Fiber formation takes place in a coaxial flow microchannel, using chemical or photopolymerization [39]. Mi-

crofluidic spinning has great potential for continuous fabrication of fibers with tunable morphological, structural, and chemical features [40]. Microfluidic spinning even enables cell encapsulation [41]. However, the fiber formation process of these technologies is slow, thus making large-scale fiber production unattractive.

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