Production of Sub-micron Fibers in Non-Woven Fabrics

Introduction

The latest buzz word in the fiber industry today is nanofibers. Specific applications discussed for fibers this small are artifical leathers, polishing cloths and filtration; and the fabrics construction techniques are generally nonwovens.

Denier has traditionally been the most common term used to define fiber size. However, this term becomes awkward when the fiber size is less than one denier. Therefore in meltblowing where the fiber sizes are generally less than one denier, the fiber diameter in microns is used. When fiber diameter gets below 0.5 microns, the term nanometer (10-9 meters) has come into use (See Table I).

Table 1 - Fiber Size Definitions

Term	Definition
Monofilament	A single filament of fiber used individually with a denier generally greater than 14. The size of monofilaments are usually described by the diameter in either microns or inches (mils).
Denier	Weight-per-unit-length measurement of a linear material defined as the number of grams per 9000 meters. Can refer to either an individual filament or a bundle of filaments (yarn).
Decitex	Similar to denier expect it is the weight in grams of 10,000 meters of a yarn or fiber.
Microfiber	Primarily a marketing term used for multifilament yarns where the individual filaments have a denier less than one. A typical one denier polyester fiber has a diameter of approximately 10 microns.
Micron *(Sized Fibers)	When fiber size is less then 0.3 denier it is best to define the size in terms of its diameter in microns (10-6 meters).
Nanofibers	Terms used for fibers with diameters less than 0.5 microns. Typical nanofibers have diameters between 50 and 300 nanometers. They can not be seen without visual amplification (See Table II)

* Other terms often used are microdenier, submicron and superfine

Today meltblowing is the primary source for small diameter fibers. Considerable research has gone into production of smaller diameter meltblown fibers, but the smallest routine commercial fibers are generally in the 2 micron size range. Fibers of such size can today be produced at ~0.5 grams/hole/minute.

Electro spinning is a much reported, but to date minimally commercialized process to generate smaller fibers. Electrospun fibers generally range in size from 50 to 300 nanometers or larger. This process has a production rate in the range of only ~0.03 grms/hole/minute. Despite the commercial shortcomings of this process, research has shown that the presence of only a very minor amount of such small fibers can greatly improve the filtration properties of a filtration laminate and this has led to some commercial applications.

To date, multi-component fibers (more then one polymer) have been less used in micro-filtration than meltblown fibers, and they are far less heralded for their small size than electrospun fibers. However, modern melt spinning distribution system technology has clearly demonstrated the capability to produce fibers with smaller size and better consistency than either of the two above techniques. In addition, micro-sized (1-10 microns) and nano-sized (<1 micron) multicomponent fibers can be produced with much improved production rates, economics and physical properties over the other systems, and with even broader polymer choice capabilities. Multicomponent fiber sizes as small as 40 nanometers have now been demonstrated at commercially attractive production rates.

Electrospinning

The manufacturing technique most often associated with polymeric nanofibers is electrospinning (Figure 1). In this technique, a polymer is dissolved in a solvent (polymer melts can also be used) and placed in a glass pipet tube sealed at one end with a small opening in a necked-down portion at the other end. A high voltage potential (>30kv) is then applied between the polymer solution and a collector near the open end of the pipet. This process can produce nanofibers with diameters as low as 50 nanometers, although the collected web usually contains fibers with varying diameters from 50 nm to 2 microns. The production rate of this process is measured in grams per hour. Therefore, unless the production rate of this technique can be increased by several orders of magnitude, the cost of nanofibers production will continue to relegate them to a laboratory curiosity or highly specialized end uses.

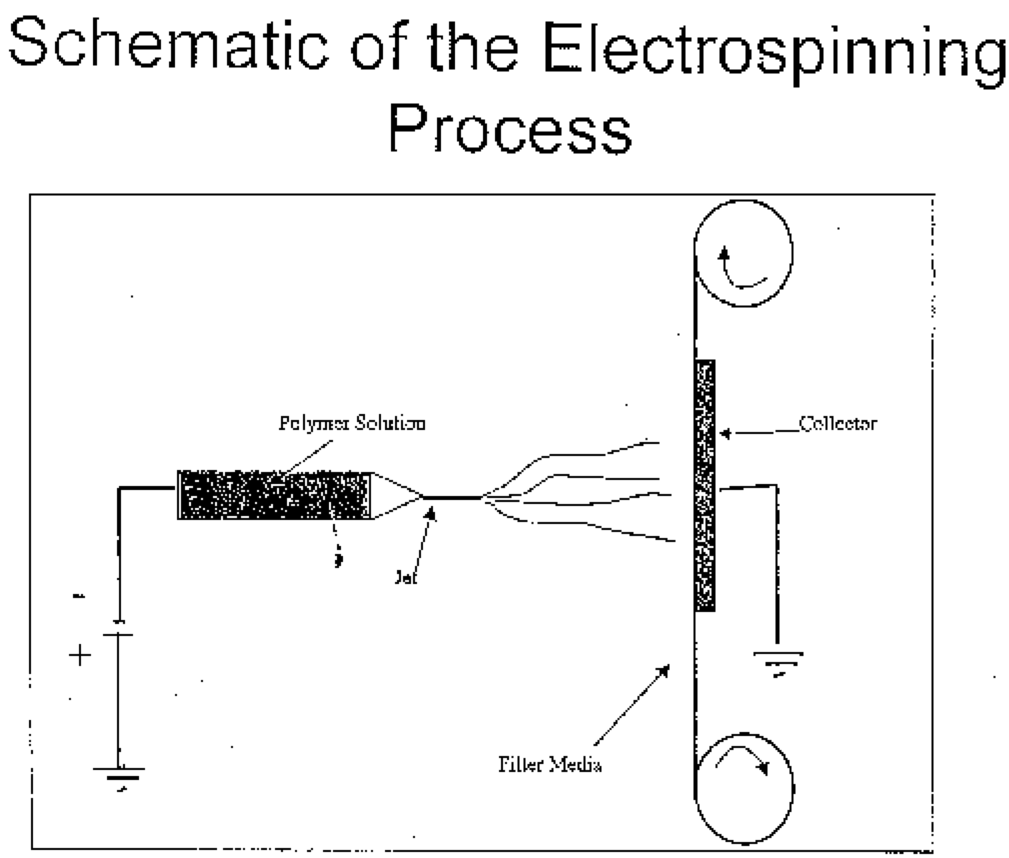

Figure 1.

In commercial filtration applications, nanofibers are typically disposited on a pre-existing substate such as a meltblown fabric. The resulting outer layer of nanofibers greatly enhances liquid retention and decreases the water contact angle as well as compresses the overall filtration properties of the fabrics. Generally, very little bonding occurs between the fabric substrate and the nanofibers web, the results of which means the nanofibers can be easily pulled away from the substrate.

Meltblowing

As mentioned earlier the most common technique used to produce small diameter fibers is meltblowing. However, success with this process to consistently make fibers with diameters below one micron has been limited. Recently Nanofiber Technology, Inc. of Aberdeen, North Carolina has claimed to produce nanofibers by meltblowing with a modular die. NanoTechnics of Korea recently showed samples of meltblown fabrics with nanofibers of consistant diameter on the surface at INDA'S Filtration Exhibition in Washington, D.C. Although the production techniques were not disclosed, microscopic examination of the sample indicated a meltblowing technique was used.

The meltblowing technique lends itself to the use of thermoplastic polymers in a relatively inexpensive spinning process. The technique does appear to have the potential to make large quantities of polymeric nanofibers at a reasonable cost. However, there are still technical and economic concerns. One concern is the broad range of fiber diameters produced (this could be of advantage in some applications), and the other is the cost of spinning equipment versus the production rate. Despite these concerns, this technique, if perfected could take nanofibers production from a limited basis to much larger commercial future.

Multi-Component Fiber Spinning

While multi-component fibers are not new per se, polymer distribution technology allowing the economical production of micro and nano-sized fibers is new. Spin pack hardware components have historically been manufactured by conventional methods such as milling, drilling, etc. Alternatively, the most modern system uses techniques similar to printed circuit board technology to manufacture the spin pack components. These are then used to very accurately distribute polymers in the extremely small area available in the spin pack (extrusion die). This has recently led to many innovations which are economical and practical for production of micro and nano-sized fibers with fiber densities and spin pack sizes applicable to large modern spunbond and meltblown production lines.

The most researched multicomponent approach is the production of islands-in-the-sea (INS) fibers (Figure 2) using a standard spinning process. This technique is commonly used for production of polishing cloth and high end artifical leathers. In this Figure 600 islands were used and the composite fiber has a final drawn denier of one. The production rate was approximately 0.5 grams/minute/hole. Polypropylene, polyester and nylon have all been used for the island polymer, with a dissolvable polymer used as the sea polymer. The resulting nano fibers after dissolving the sea polymer had diameters of approximately 300nm. Unlike electrospinning and meltblowing, the nanofibers produced with this technique have a very narrow diameter range. The projected cost of these fibers is low enough for many commercial applications, particularly since many applications include only a small percentage of nanofibers combined with standard melt spun fibers.

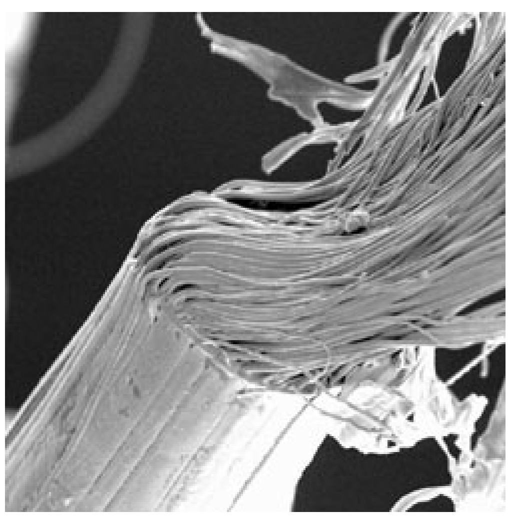

Figure 2 INS Fiber

These fibers have until recently only been spun as filament or staple fibers; however, since the new spin pack filament densities are the same as for a spunbond spin pack the translation to a direct spunbond format was acheivable .

Another bicomponent spinning technique that gives small diameter fibers is splittable pies (Figure 3). These fibers, generally made from PET and nylon, have been produced in filaments yarns for over 30 years in Asia. More recently, co-polyesters have replaced the nylon. These types of fibers have already been spun on pilot spunbond lines and in at least one commercial product. However, in the spunbond format, these fibers after splitting do not reach into the sub-micron range (See Table II).

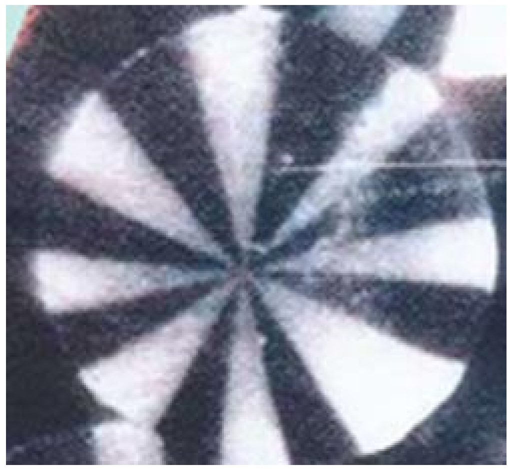

Figure 3

For the nanofibers range we need to spin this type of fiber in the melt blowing format. Bicomponent melt blown fibers are already commercial (See Figure 4) in sheath/core, side-by-side and tipped trilobal geometries.

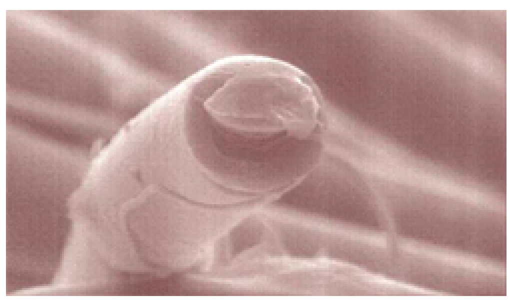

Figure 4

Therefore, another approach to the use of multi-component fiber spinning to manufacture nanofibers is to make splittable fibers in a melt blowing process. The number of segments needs to be 16 or greater, and the best approach might be to use a water-dissolvable polymer in a small ratio along with PET or PP segments. One potentially ultimate approach is to meltblow INS fibers that contain >600 island fibrils that would have diameters as low as 50nm and would act as a regular melt-blown fiber through fabric formation, after which the sea polymer is dissolved and only the nanofibers are left.

Bicomponent vs. Meltblown and Electrospun Fibers

Table II is the table previously referred that compares a few of the endless possibilities for micro and nano-sized fibers produced from multi-components vs. conventional meltblown and electrospun fibers. The conventional process fibers in the Table are all homopolymer products, and the others are all multi-components either segmented pies or islands-in-a-sea. The fiber size and the fiber surface area are shown for each fiber type. While conventional meltblown fibers and conventional electrospun fibers both offer much smaller size than conventional staple or spunbond fibers, several of the listed bicomponent fibers are much smaller than either conventional meltblown or electrospun fibers.

The islands-in-a-sea fibers presented in the table are all manufactured from either 30 islands (Fibers #6, 8, &10) or 600 islands (Fibers #7, 9, & 11) fibers. The reduced fiber size and increased surface area resulting from the larger island count clearly shows the advantage of such fibers, which are only available from the modern multi-component manufacturing technique previously discussed. Comparison of the cross shaped islands (Fibers #8 & 9) with round islands (Fibers #6 & 7) also shows the surface area advantage of shaped islands. Fiber #11, (the nanotube from 600 islands), is really impressive in both size (40 nanometer wall thickness) and surface area (33.6 sq-mt/gram). This fiber is so small and light weight that little more than a single gram of it would circle the earth at the equator. (Figure 5)

Figure 5

The final column in the table is the approximate comparative production rates in terms of grams/hole/minute (hole meaning an extrusion orifice). This is directly related to manufacturing cost and extrusion equipment capital requirements. The smallest bicomponent fibers compare favorably with the conventional processes and are indeed far superior to the electrospun process.

A final item to emphasize is that even in the case of the smallest multi-component stable and spun bond fibers, these micro or nano-sized fibers have excellent tensile properties (similar to conventional staple and spunbond fibers). This is because these tiny fibers are crystallized and oriented in the same manner as in processing conventional fibers. Meltblown and electrospun fibers on the other hand are low in crystallinity and orientation and are therefore very weak. These latter fibers are so weak that they are often only used in composites with larger and stronger fibers. The multi-component fibers can much more often be used without the need for larger, stronger fibers to create fabric strength. Alternatively, with modern technology, multi-component meltblown, staple, filament, or spunbond dies can be designed so that the right number and size of nanofibers are simultanteously produced in combination with just the right number and size of larger fibers to achieve the desired customized properties.

Table 2

MICROFIBER COMPARISON

FIBERI.D.	**MFG.PROCESS**	**FIBER DESCRIPTION**	**FIBER CROSS SECTION**	**FIBER SIZE (Microns)**	**SIZE (Microns) FIBER SURF. AREA (Sq-mt/Gr)**	**PROD. RATE(Gr. Per min. per fiber)**
CONVENTIONAL PROCESSES						

PROCESSES						
1	Conventional Staple or Spunbond	One denier fiber, Homopolymer	Round	10.1	0.3	0.67
2	Conventional Meltblown	Two micron fiber, Homopolymer	Round	2.0	1.4	0.5
3	Conventional Electrospun	Size/shape as best reported	Round	0.3	9.5	0.02
SEGMENTED PIE PROCESSES						
4	Segmented Pie Staple or Spunbond	One denier fiber, 32 Segment Pie	Pie Segments	Ea. Segment = 1.0 Arc X 2x5.1 Legs	Ea. Segment = 3.2	0.67
5	Segmented Pie Meltblown	Two micron fiber, 16 Segment Pie	Pie Segments	Ea. Segment = 0.4 Arc X 2x1.0 Legs	Ea. Segment = 8.7	0.5
ISLANDS-IN-A-SEA PROCESSES						
ROUND ISLANDS						
6	Islands-in-a Sea Staple or Spunbond	One denier fiber, 50/50 Islands/Sea, 30 islands	Round Islands	Ea. Island = 1.3	Ea. Island = 2.2	0.3
7	Islands-in-a Sea Staple or Spunbond	One denier fiber, 50/50 Islands/Sea, 600 Islands	Round Islands	Ea. Island = 0.3	Ea. Island = 9.8	0.3
CROSS SHAPE ISLANDS						

8	Islands-in-a Sea Staple or Spunbond	One denier fiber, 50/50 Islands/Sea, 30 Islands	Cross Shape Islands	Ea. Island = 0.4 Wide X 0.2 Long	Ea. Island = 5.9	0.3
9	Islands-in-a Sea Staple or Spunbond	One denier fiber, 50/50 Islands/Sea, 600 Islands	Cross Shape Islands	Ea. Island = 0.4 Wide X 0.9 Long	Ea. Island = 26.5	0.3
NANOTUBE ISLANDS						
10	Islands-in-a Sea Staple or Spunbond	One denier fiber, 50/50 Islands/Sea, 30Islands	Microtube Islands, 50% Hole	Ea. Tube = 1.2 OD X 0.2 Wall	Ea. Tube = 7.5	0.15
11	Islands-in-a Sea Staple or Spunbond	One denier fiber, 50/50 Islands/Sea, 600 Islands	Microtube Islands, 50% Hole	Ea. Tube = 1.2 OD X 0.04 Wall	Ea. Tube = 33.6	0.15

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