



Fiber Innovation Technology, Inc.

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***SYNTHETIC SPLIT MICROFIBER
TECHNOLOGY FOR FILTRATION***

by

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Introduction

Fine diameter fibers have always been of interest in filtration applications. It is widely known that, in general, finer fibers are required to achieve finer filtration properties. Synthetic meltblown fabrics and microglass materials have been the main options available for companies interested in participating in markets where finer fibers are required. Meltblown fibers typically range from between 3-6 microns in diameter (with some as low as 1 micron), whereas glass microfiber diameters are available down to nanometer sizes (250 nanometers = 0.25 microns).

Meltblown and microglass materials have limitations that have kept them from expanding their usage into a broad range of filtration technologies and applications. Meltblown fabrics are typically produced from one type of melt polymer and in a narrow range of fiber diameters. The fabric can be electrostatically-charged to increase its first step (clean) efficiency. The fabrics are typically weak and are used in combination with support media (such as polyester spunbond fabrics) to add enough strength to survive the use environment. Meltblowns are usually layered to optimize their filtration properties (proper balance between penetration, dirt holding capacity, and clean pressure drop) meaning that a number of layers of meltblown fabrics are needed to meet the specified application requirements. This becomes an expensive way to meet a customer's needs. And meltblown fabrics are difficult and expensive to incorporate into other nonwoven filter media structures such as carded, airlaid, needlepunch, and wetlaid composites.

Glass microfibers are more flexible to use than meltblown materials but have length and environmental limitations. Microglass has been successfully processed on wetlaid systems for years to produce fine fiber containing high efficiency filtration materials. They can be easily blended with other non-glass fibers. Glass fibers can not be electrostatically-charged so must rely on their fine diameters to mechanically increase filtration efficiency of the filter medium. Extremely fine structures can have very high clean pressure drops. Their short length (usually less than 0.25") means that they are not easily be run on textile-based nonwovens equipment (carded, long-fiber airlaid, needlepunch, and hydroentanglement). Certain glass chemistries contain elemental boron which reduces process yields by migrating into manufactured silica wafers during semiconductor production. Microglass is also a known skin irritant and can be easily inhaled into the lungs when handled dry, making it a more difficult fiber for machine operators to work with.

A new series of synthetic fine fibers has been developed that do not have a number of the deficiencies of these two products. They are spun at standard deniers and can be easily processed and split into micro-denier fibers on textile-based and wetlaid nonwovens processes.

The fibers can be blended and processed with other fibers for product designs that meet customer needs. These fibers are both based on spinning fibers of at least two dissimilar polymers and can be spun into either segment-splittable or dissolvable “islands-in-the-sea” formats. The fiber diameters currently available are between 2-3 microns, with below 1 micron being targeted. The fiber segments can be electrostatically charged. These fibers bring value to applications where properties such as sound and temperature insulation, fluid holding capacity, softness, strength and durability, luster, high surface area, barrier property enhancement, and filtration performance are needed. This paper will focus on the use of splittable fibers in filtration applications.

Splittable Fiber History

The technology was first developed commercially in Japan in the mid to late 1960’s for synthetic suede fabrics¹. Staple fibers were spun from two dissimilar polymers, a polyester (PET) and copolyester (co-PET) as a sea of co-PET around islands of 0.1 denier PET. The 3.0 denier fibers were carded on standard textile-based nonwoven equipment and consolidated into fabrics by needlepunching to produce a felt. The resultant fabrics were then coated with elastic polyurethane and chemically treated to dissolve the co-PET sea, leaving a fine diameter fiber network of the other polymer inside the polyurethane coating. The product had the soft feel of suede and was inexpensive to produce. An example of this type of fiber is indicated in Figure 1.

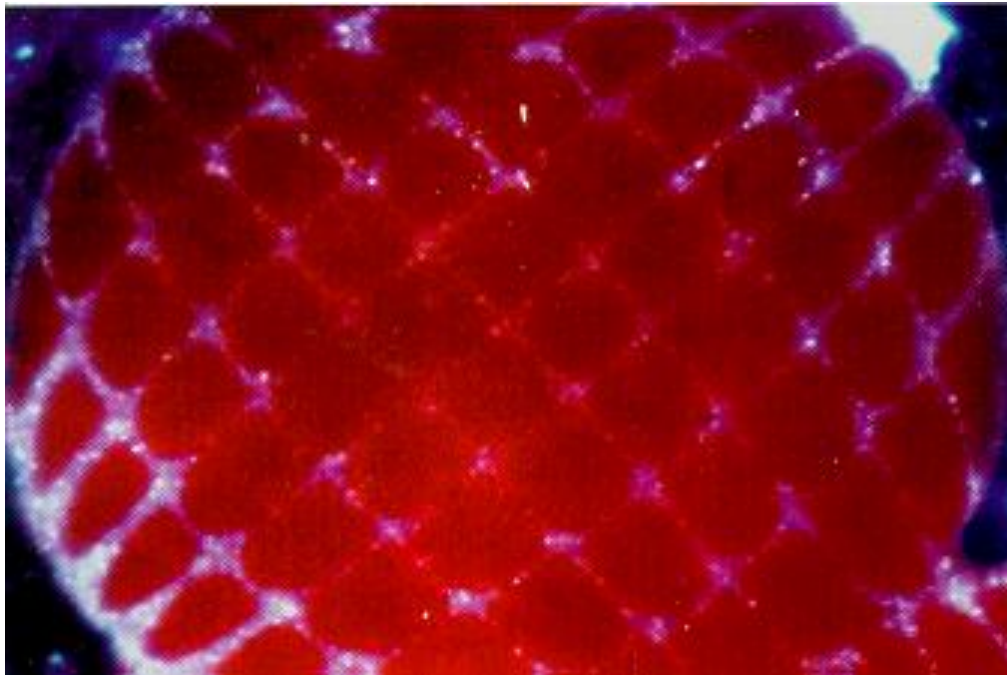


Image provided by Hills, Inc.

Figure 1. Cross-sectional Photomicrograph of a Splittable Fiber – “Islands-in-the-sea” Format²

Since that time, other forms of synthetic splittable fibers have been produced including segmented fiber cross-sections. An example of the cross-section of this type of fiber is shown in Figure 2. The fibers are again spun from 2 dissimilar polymers. The segments alternate between polymer types. The number of fiber segments ranges from 2 to 32 in a round fiber but typical production fibers are usually 16 segments. The segments separate with the addition of energy to cause the segments to part. The polymer types, cross-sectional shape, and die pack geometry all affect the amount of energy required to cause the fibers to split. These factors are used to control where the fiber will split in the nonwoven producing process.

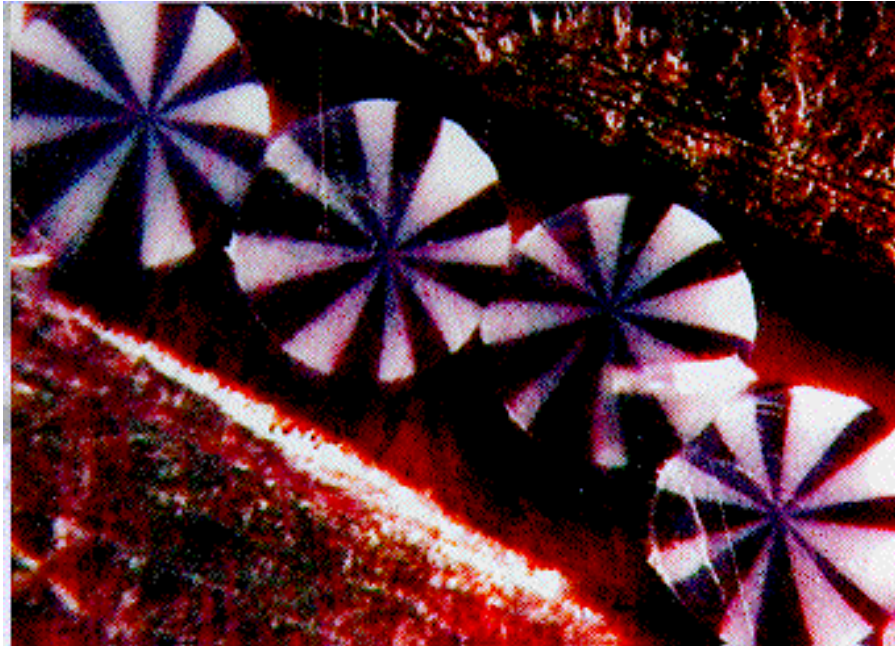


Image provided by Hills, Inc.

Figure 2. Cross-sectional Photomicrograph of A 16-segment Splittable Fiber²

Filtration Mechanisms

Extremely fine fibers of two dissimilar synthetic polymers fit well into filtration applications where the dominant mechanisms are (1) interception, (2) Brownian motion, (3) coalescence, (4) electrostatic effects, and (5) triboelectric effects. These filtration mechanisms are defined as follows³:

- (1) Interception: Filter media can be thought of as sieves that mechanically entrap particles larger than the largest pore size in the filter medium. Imagine a screen of one pore size being challenged with a particle stream of various diameters. The smaller diameter particles will in general pass through the larger screen openings. Those particles captured will typically be larger than the opening in the screen and will start to build a filter cake that will remove successively smaller particle diameters. This will continue until the filter cake becomes plugged. The particles that stop the fluid flow through the cake will

be the smallest particles in the fluid stream. The screen pore size distribution is the controlling design criteria for how the media will work in the filter.

- (2) **Brownian Motion:** Some particles being filtered may be small enough to react when bombarded by the molecules in the moving fluid stream. The motion of the particle will become more random as it is hit by nearby molecules. This may cause the particle to leave the fluid stream and contact a fiber and become attached to the fiber surface.
- (3) **Coalescence:** This describes the process of removing a discontinuous fluid phase from a continuous phase by growing progressively larger droplets of the discontinuous phase. The fluids can be oil in air, water in fuel, oil in water, and a number of other combinations, but in each case a combination of two immiscible fluids. The process is started by initiating droplet growth of the discontinuous phase on an open fiber mat, propagating into larger droplets by increasing the flow turbulence to cause the initial droplets to hit each other with enough force to combine into larger droplets, and finally to rise or fall out of the continuous fluid phase as defined by Stoke's Law. Since the droplet rise or fall rate is governed by the square of the radius of the droplet, larger droplets will be easier to remove than small ones.
- (4) **Electrostatic effects (Electrets):** Particles in nature typically possess a naturally occurring charge. Imparting a charge to fibers can significantly enhance the capture efficiency for these particles when traveling at low velocities. The electrical charges on the particle and fiber attract each other and add to the capture efficiency of the filter medium⁴.
- (5) **Triboelectric effects:** When fluids flow across surfaces, they generate electrical effects as a function of the rubbing of the fluid and solid surfaces together. One example of this effect is the electric charge generated when rubbing a glass rod with wool. Polymers have natural relative charges on the triboelectric scale. When two materials on opposite ends of the scale are combined in the same material, they generate an electric dipole under flow conditions that causes electrostatic effects to take place and enhances the efficiency of filter materials.

Splittable synthetic fibers enhance each of these filtration mechanisms and increase the filtration performance of media working in each of these regimes. The very nature of extremely fine diameter fibers makes them suitable for filter applications where interception, Brownian motion, and coalescence are the dominant/significant mechanisms. Also, the fact that these fibers are spun from 2 dissimilar polymers means that the choice of polymers can define a fiber that can be electrostatically charged and/or triboelectrically charged under flow conditions. Thus, these fibers are extremely versatile in their filtration usage and can be the basis for a new series of proprietary filter materials that will create a marketable advantage with a market head start for the media supplier if properly applied.

Nonwoven Processes where Splittable Fibers can be Applied

Carding:

A series of segmented synthetic splittable fibers has been developed that will split when processed through gentle carding systems such as cotton and semi-worsted cards. The fibers are produced from polyester and nylon 6 and are spun into a 16-segment 3 dpf X 2" crimped fiber

(for cotton system (other lengths and deniers can be produced for semi-worsted system). The individual split fiber segments have effective diameters in the range of between 3-4 microns. The fiber is blended up to 30% of the fiber blend with other fibers. The fiber must be properly preblended and opened to maximize blend uniformity before carding. Worker and stripper loading must be considered when running this fiber because the split fiber has 16 times the number of fibers that must be processed through the system. A number of other polymer combinations are under development including polypropylene for electrostatic charging and blends of polymers for enhanced triboelectric properties. Figure 3 shows the fiber before carding.

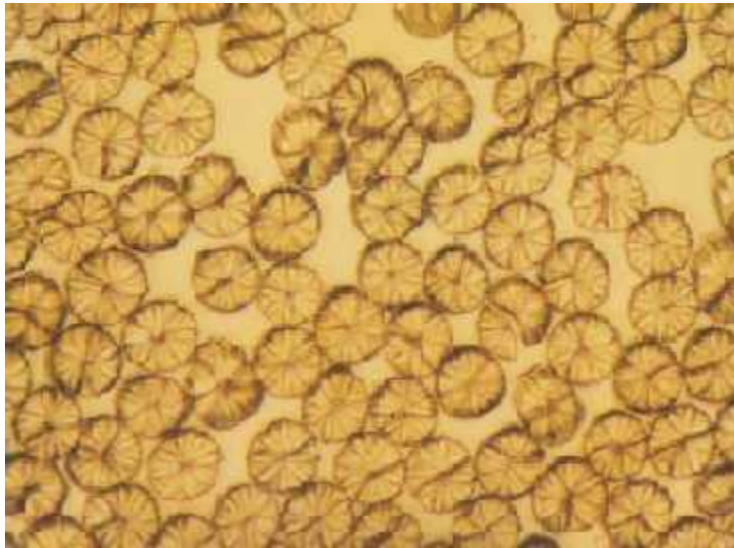


Figure 3. Photomicrograph of Card-splittable Fiber Before Splitting

Figure 4 is a cross-sectional photomicrograph of the card-split fiber. The individual split segments can be clearly seen. Notice that the fiber segments are pie-shaped. This shape should be an advantage in filtration materials for lowering the clean pressure drop of materials produced from these fibers.

Wetlaid:

Splittable synthetic fibers have been produced in short cut form with a water dispersible finish. Polymer blends include polypropylene/nylon 6 and polypropylene/polyester. The fibers have been produced as 16-segment 4.1 dpf X 0.24" without crimp. When formed into handsheets with minimal opening processing, the physical properties of the handsheets match those of commercially available meltblown polypropylene materials as shown in Table 1. Split fiber segments range from 3-4 microns. Order of addition of furnish components will need to be addressed for each specific fiber blend produced.

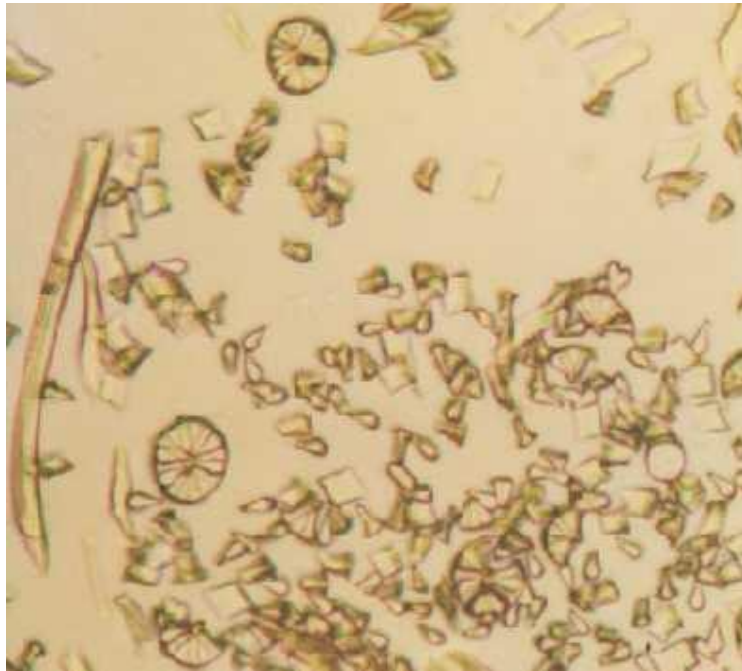


Figure 4. Cross-sectional Photomicrograph of Card-Splittable Segmented Fiber After Carding

Property	Wetlaid Short Cut Nylon 6/Polypropylene	Commercial Meltblown
Basis Weight (gsm)	55	65
Frazier Permeability (cfm@ 0.5" H ₂ O)	265	250
1 st Bubble ("H ₂ O in diesel fuel)	4.0	4.2
Thickness (mils)	14	14
Strip Tensile (lb/inch)	1.0	0.3

Table 1. Wetlaid Splittable Fiber Versus Commercial Meltblown Physical Property Comparison

Airlaid (Long Fiber Type):

These fibers have been successfully processed in fiber blends through a Rando Webber as high as 50% of the fiber blend. The fiber opened and split well in the machine and produced a uniform product with micro-denier fiber segments. When a card is used as part of the fiber opening system for the Rando (or the airlaid process is a Fehrer-type system), care should be

taken to select a splittable fiber blend percentage that will successfully process through the card without jamming the worker and stripper sections.

Airlaid (Short Fiber Type):

The wetlaid shortcut version of the fiber has been successfully processed through a DanWeb Forming airlaid system up to 90% of the fiber furnish. The fiber was fed to the unit through a transport fan that opened and split the fiber into individual segments and formed it into an airlaid sheet. The resultant web was bonded with 10% binder fiber and was extremely soft to the touch. Blends with woodpulp and other fibers are expected to process well and can carry the splittable fiber through the hammermill section, if needed. Blend levels will require definition for each specific application.

Hydroentangled:

Splittable synthetic fibers have been produced with cross-sections that will split when subjected to high-pressure water jets without splitting in the card. The fibers are processed as-spun into nonwoven products as standard textile fibers. The web is then passed through a hydroentanglement unit that splits the fibers and causes them to wrap around themselves and other fibers in the blend to enhance the tensile and toughness properties of the product. A curve describing the relationship between hydroentanglement pressure and web weight is presented in Figure 5.

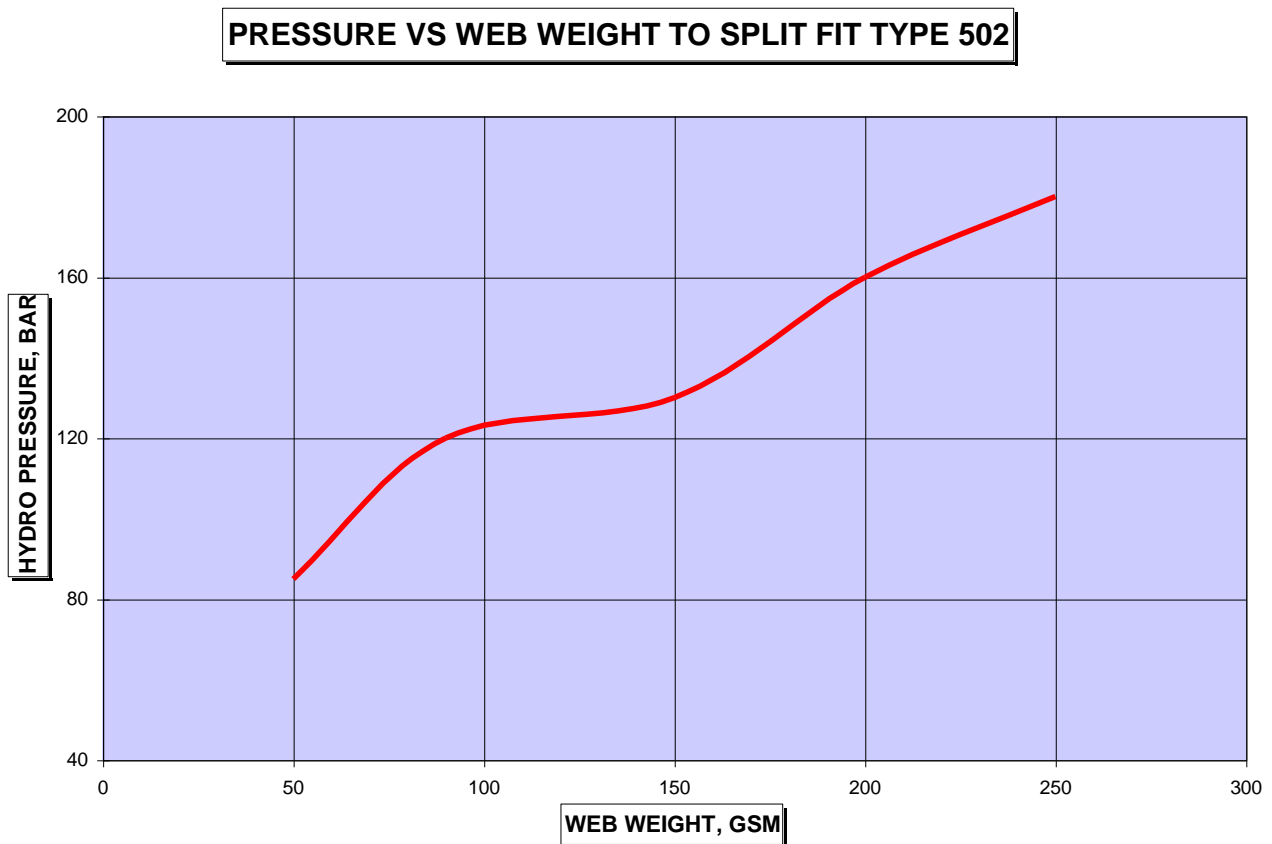


Figure 5. Energy Required to Split Various Web Weights Of Splittable Fibers

Islands-in-the Sea Splittable Fibers

These synthetic fibers are spun with a dissolvable “sea” that must be removed, leaving “island” fibers of extremely fine diameters. The sea can be any number of dissolving polymers including polystyrene (soluble in organic solvents) specific co-polyesters or poly(lactic acid) (dissolvable in a 3% alkali treatment, for 3 minutes at 90°C), or polyvinyl alcohol (PVA), thermoplastic starches, or another co-polyester, which are soluble or dispersible in hot water. Commercially available fibers have offered 37 islands of nylon 6 in an alkali-soluble co-polyester sea. At a pre-dissolution denier of 2-3, the resulting microfibers from this fiber have diameters of about 6 microns. New fibers currently being commercialized also offer island microfibers of many different polymers, and trials are underway to define the process to produce higher numbers of islands in each fiber. With higher numbers of islands, of course, the resulting microfiber diameter decreases. Lab work indicates that as many as 600 islands can be included in each islands/sea fiber, which, after dissolution, could produce microfibers only 1 micron in diameter. Staple and short cut fibers are available for nonwovens and filament yarns will soon be available for textile applications. In all cases, the fine fiber diameters available lend themselves to new filtration applications that were not commercially achievable with synthetics before.

The performance of the microfibers can also be adjusted to some degree in the fabric-forming process, by controlling whether liberation of the microfibers occurs before or after thermal, chemical, or mechanical bonding steps. For instance, removing the sea and then forming a wetlaid fabric with the microfibers results in a more even distribution of the microfibers than forming a wetlaid fabric of the island/sea fibers and then dissolving the sea.

Potential Filtration Applications

Many potential applications exist where synthetic splittable fibers can be used to add value and create a marketing advantage and head start to market for innovative filter suppliers. These materials can be used to produce:

- high efficiency air filtration materials. The micron-sized fiber segments add mechanical filtration properties to the filter medium. Also, two different dissimilar polymers can be selected that will generate triboelectric properties under flow conditions. The two polymers may also be electrostatically chargeable to enhance first-step filtration properties. These filtration mechanisms, when combined properly, may be able to create a higher efficiency, lower clean pressure drop filter materials that will last longer before plugging in both air and liquid applications.
- low-to medium efficiency materials for HVAC applications. The addition of a small amount of splittable fiber should increase the dust spot efficiency of a filter material significantly due to its low fiber diameter in relation to the other fiber diameters currently being incorporated into the filter medium.
- extremely fine, highly uniform veils as components of support media for additional strength and burst properties or as release surface facings for cleanable filter applications where it is important to keep the captured dust from penetrating into the depth of the filter medium.

- flex-resistant materials. In pulsing applications where the filter medium is continuously flexed but also requires stiffness, splittable synthetic fibers add a high degree of reinforcement to the filter medium because there are at least 16-times the number of fibers available for reinforcement when they are split for segmented fibers (33 times or more for islands-in-the-sea fibers).
- replacing microglass in air and liquid applications where glass fibers are no longer acceptable because of product contamination and worker exposure.

Conclusion

Filter manufacturers are constantly looking for innovative materials that give them an advantage in the marketplace. They will actively work with companies that offer them a better material or exclusivity/head start that will position them ahead and away from their competition. Splittable synthetic fibers are an entire new range of materials that open innovative product development opportunities in filtration. These “tools” will allow the filtration companies that have an understanding of their markets and have identified unmet needs the ability to be the first to market to fill available niches, command higher selling prices, support the perception by their customers as technically innovative, and change their subordinate supplier relationship to one of a true partnership.

References:

1. U.S. Patent No. 3,705,226. Okamoto et al. “Method for Manufacturing Fibrous Configuration Composed of a Plurality of Mutually Entangled Bundles of Extremely Fine Fibers”.
2. Gillespie, Don B. Private Communication. Fleissner Incorporated, 12301 Moores Chapel Road, Charlotte, NC 28214.
3. Homonoff, Edward C. “Utilizing Multilayered Materials for Filtration and Separation”. Filtration News, March/April 2000.
4. Tsai, Peter P., Huang, Hsu-Yeh, and Wadsworth, Larry C. “Electrostatic Properties of Fibrous Electret Filters”. 1998 TAPPI Nonwovens Conference and Trade Fair.