MULTI-COMPONENT FIBER TECHNOLOGY FOR MEDICAL AND OTHER FILTRATION APPLICATIONS.

INTRODUCTION

Meltblowing has been the primary source for micro-filtration 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 (~2000 nanometers). Fibers of such size can today be produced at ~0.5 grms/hole/minute.

Electrospinning is a much reported , but to date minimally commercialized process to generate smaller fibers. Electrospun fibers are generally in the size range of ~0.3 microns (~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.

To date, multi-component fibers 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) multi-component fibers can be produced with improved production rates, economics and physical properties over the other systems, and with even broader polymer choice capabilities. Multi-component fibers sizes of ~0.04 microns (~40 nanometers) have now been demonstrated at commercially attractive production rates. Multi-component fiber production is available in staple, continuous filament, spunbond, and meltblown processes.

MULTI-COMPONENT FIBER CROSS SECTIONS By far the most common type of multi-component fibers are bicomponent fibers (consisting of two polymer components).

Table 1 depicts some common bicomponent fiber cross sections. The major types include:

- Sheath/Core fibers, most commonly used as binder fibers.

- Side by side fibers, most commonly used to produce bulky, self-crimping fibers.

- Tipped products, most commonly used in limited specialty products.

- Segmented products, where by chemical, thermal and/or mechanical methods, the segments split into small individual fibers.

- Islands-in-a-Sea products, where the sea is normally dissolved away to leave only the very small islands.

- Various mixes of two or more fiber types to make such specialized products as yarns or fabrics having multiple cross-sections.

More explanations of bicomponent fiber cross sections and uses are available in the published literature.

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 used to very accurately distribute polymers in the extremely small area available in the spin pack (extrusion die). This has very recently led to many innovations which are economical and practical for production of micro and nano-sized fibers. As will be evident from this paper, such technology is leading to development of many new and exciting micro and nano-sized fiber products.

EXAMPLES OF NANOFIBER BICOMPONENTS

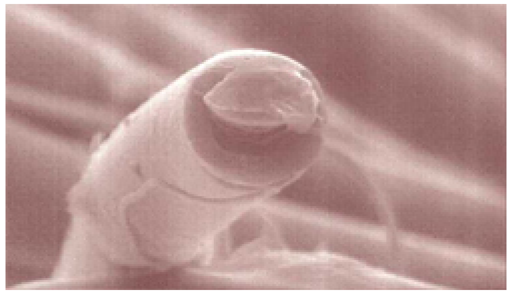

Fig 1

Figure 1 is a photomicrograph of a sheath/core meltblown fiber, where the PE sheath is used as a bonding material. This particular fiber is the first cross section shown, not so much for its small size as it is to demonstrate how modern bicomponent technology is also expanding the use of existing micro-sized fibers.

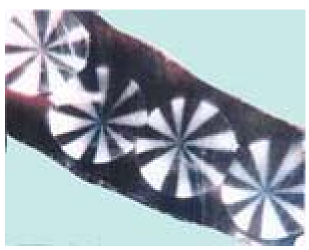

Fig 2

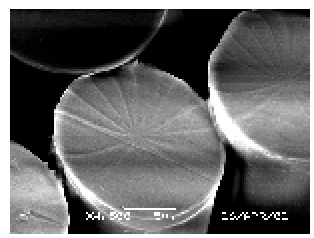

Fig 3

Figure 2 is a sixteen segment pie fiber prior to splitting, and Figure 3 is a 32 segment pie prior to splitting. These two photo-micrographs also show how the ratios of the two polymers can be easily changed (50/50 ratio in Figure 2 and 20/80 ratio in Figure 3). In a later table we shall review the size of the individual segments from 16 segment and 32 segment pies vs. other micro-fibers.

Fig 4

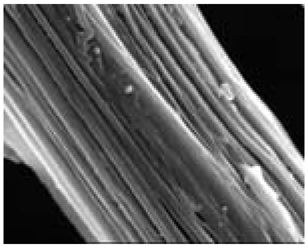

Fig 5

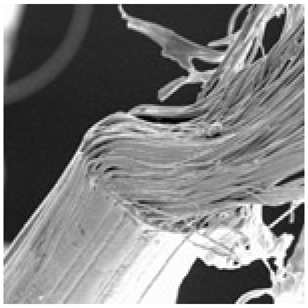

Fig 6

Figure 4 is a fiber with 64 islands-in-a sea. Until recently, this island count was the record for fibers produced at normal fiber production rates. However, recently we have produced fibers with more than 1000 islands at normal rates. Figures 5 & 6 show fibers with 240 and 600 islands respectively, depicting the fibers both before and after dissolving the sea component. Please notice the uniformity of the diameter of the tiny continuous islands (in contrast to the broad fiber size distribution of meltblown fibers). In the case of 600 islands produced from a one denier fiber, each island is ~0.3 microns (300 nanometers) in diameter.

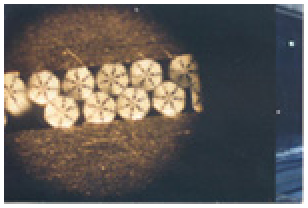

Fig 7

Figure 7 is a very early version of an islands-in-a-sea fiber with shaped (non-round) islands. In this case there are 24 islands with “cross shapes”. In a later table we will show how shaped islands can result in continuous fibers of incredibly small size.

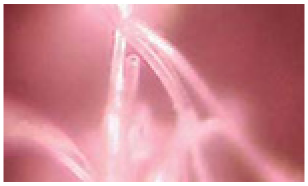

Fig 8

Figure 8 is one of the smallest cross section fibers we have made to date. What is shown are islands from an islands-in-a-sea, with the most unique quality being that the islands are actually hollow. Such hollow islands remaining from a one denier, 600 islands-in-a-sea fiber have a wall thickness of only ~0.04 microns (40 nanometers). This is made in a proprietary process from which we call the islands “Hills Nanotubes”.

BICOMPONENT vs. MELTBLOWN & ELECTROSPUN FIBERS

Table 2 on page 5 is the table previously referred to comparing a few of the endless possibilities for micro and nano-sized fibers produced from bicomponents vs. conventional meltblown and electrospun fibers. The conventional process fibers (Fibers 1-3) are all homopolymer products, and the others are all bicomponents, either segmented pies or islands-in-a-sea. The fiber size and the fiber surface area are shown for each fiber type. While the conventional meltblown fibers (Fiber 2) and the conventional electrospun fibers (Fiber 3) both offer much smaller size than the conventional staple or spunbond fibers (Fiber 1), several of the listed bicomponent fibers are much smaller than the conventional meltblown and electrospun fibers.

All the bicomponent fibers in the table are from staple or spunbond processes except the 16 segment pie meltblown fiber (Fiber 5). With modern melt distribution technology, such a meltblown fiber can be made today at rates comparable to conventional meltblown. While the small size and large surface area of this fiber are improved relative to the conventional meltblown fiber, it is still significantly inferior in these respects to other bicomponent fibers that are shown in the table produced from staple or spunbond processes. Even the simple islands-in-a-sea fiber produced with 30 round islands (Fiber 6) is significantly superior to the conventional meltblown fiber.

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 bicomponent manufacturing technique previously discussed.

Comparison of the cross shaped islands (Fibers 8 & 9) with the round islands (Fibers 6 & 7) also shows the 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/gr.) This fiber is so small and light weight that only about a single gram of it would circle the earth at the equator.

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 bicomponent staple 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 and stronger fibers. The bicomponent 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 simultaneously produced in combination with just the right number and size of larger fibers to achieve the desired custom properties.

FUTURE DEVELOPMENTS WITH MULTI-COMPONENT FIBERS

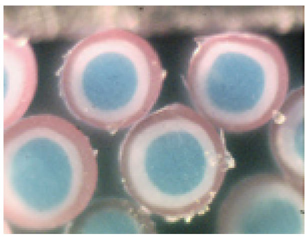

Fig 9

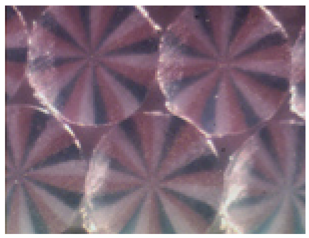

Fig 10

Fig 11

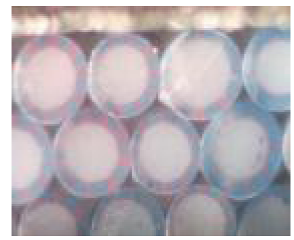

Fig 12

As impressive as these previous bicomponents are, the surface has only been scratched in the development of micro and nano-sized fibers from modern polymer distribution technology. For example, we are just now installing some
continuous filament machinery in Asia to commercialize some tricomponent fibers. Some of the cross sections that will initially be produced are shown in Figures 9 - 12.

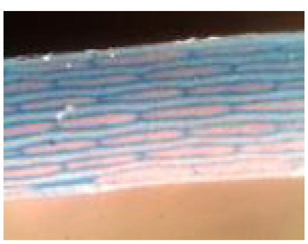

Fig 13

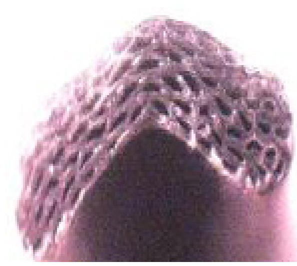

Fig 14

Figure 13 is another example of a tricomponent fiber we have just developed for a Customer. In this case, the fiber is intended for use as a key component in an MEMS device (micro electromechanical system). This entire fiber measures only 40 microns x 160 microns. By applying a voltage, the fiber will contract to act as a micro-actuator. We are now also working on ways to use this fiber as a self cleaning or variable area filter (or membrane) by changing the pore sizes via changes in voltage applied to the fiber (Figure 14).

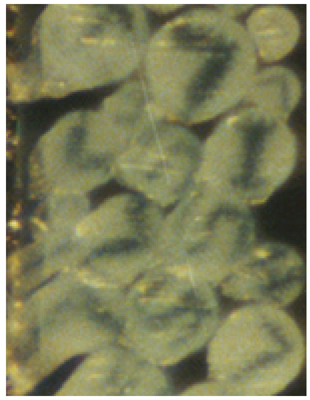

Fig 15

<u>CONCLUSION – ALL THINGS ARE POSSIBLE:</u> There is a lot of technical hype these days about nano-technology. For ages, when man-kind has needed something very small, they turned to fibers - first natural fibers, then later synthetic fibers produced from single polymers. If history applies, fibers, especially multi-component fibers, will play a major role in nano-technology of the future. As has been shown in this paper, compared to conventional meltblown and electrospun fibers, multi-component fibers can be produced more economically, stronger, more consistently, with broader polymer selection, and without practical restraint on size or shape. As a final example of what has already been accomplished, Figure 15 shows a group of fibers, each about 10 microns in diameter where, with precision extrusion of a second polymer, we have written alphabet characters in the individual fibers. Some fibers contain H's, some I's, some L's, and some S's. With modern multi-component technology, all things really are posssible.

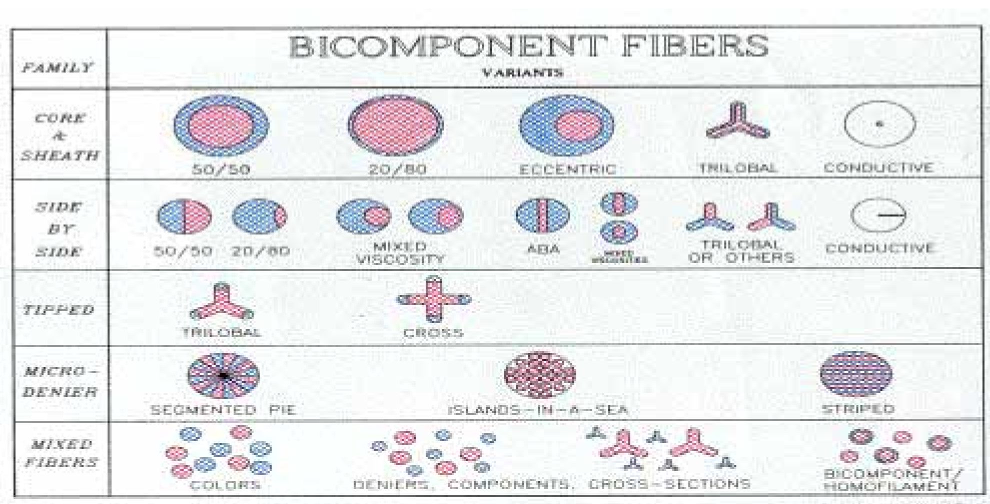

Table 2
MICROFIBER COMPARISON

FIBERI.D.	MFG.PROCESS	FIBER DESCRIPTION	FIBER CROSS SECTION	FIBER SIZE (Microns)	SIZE (Microns) FIBER	PROD. RATE(Gr. Per min.

					SURF. AREA (Sq-mt/Gr)	per fiber)
CONVENTIONAL 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	One denier fiber,	Round Islands	Ea. Island =	Ea. Island =	0.3

	Staple or Spunbond	50/50 Islands/Sea, 600 Islands		0.3	9.8	
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