Polymeric Nanofibers

Polymeric Nanofibers - Fantasy or Future ?

We are all familiar with the latest technical buzz words. In the recent past, we become aware of micro-machines, dot coms, genome, and so forth. Today the hottest new word in textiles is nanofibers. We have read about nanotubes, nanomaterials, nanomachines and now nanofibers. In its general definition, nano means one millionth (1/106) of a millimeter or 10-9 meters. When the term is applied to technology (nanotechnology), the common definition is "the precise manipulation of individual atoms and molecules to create layer structures".

Okay, so what is a nanofibers? To answer this question we first need to put a workable definition on the terms that came before such as microfiber. Table I is my attempt at quantifying the six most common terms used to describe the size of fibers. It is obvious from Table I there is a breakdown in the terms used to define fibers when the fiber size is below 0.3 denier. The term micron has not been commonly accepted and has been somewhat corrupted by the over use and somewhat ambiguous term microfiber.

Unfortunately, the term nanofibers has also become somewhat ambiguous even though the definition given in Table I is very precise. The reason for the confusion is carbon nanotubes which are an ordered array of carbon atom which can have tensile strength up to 15 x that of steel. These tubes or fibers are often called graphite or carbon nanofibers as well as nanotubes. The technology for manufacturing carbon nanotubes is very different from common fiber production techniques and the end uses are not those commonly associated with fibers. The nanofibers of interest to the fiber industry are polymeric nanofibers made from conventional and newly emerging polymers and with end uses typical of standard textiles. These fibers are the subject of this article. For these types of fibers the smallest practical size is approximately 50 nanometer as a polyester crystallite has dimensions in the order of 40 nanometer so structures approaching this size would begin to become an ordered array of atoms and would not have typical fiber morphology.

Research into production of polymeric nanofibers has been funded by the government for almost twenty years. Much of the early work was done by Darryl Reneleer at the University of Akron. The agency most interested in this area has been the U.S. Army and the Natick Solider Center looking for improved barrier fabrics for clothing. Natick recently reported that only small amounts of nanofibers on the surface of meltblown fabrics greatly enhances liquid retention and decreases water contact angle (Ref 2). Other factors such as air resistance and breathability are also expected to be significantly impacted as nanofibers are added to a nonwoven fabric (Ref. 3). However, the fact that we can manufacture nanofibers and find beneficial end uses does not sufficiently answer the question are nanofibers fantasy or future? For the answer to this we need to rephrase the question: Will the manufacturing costs of nanofibers be less than the potential value of the benefits imparted? To explore this questions we need to review potential manufacturing techniques.

The manufacturing techniques most after 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 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 two 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 mostly a laboratory curiosity.

Another technique to produce polymeric nanofibers has recently been introduced by Nanofiber Technology Inc. of Aberdeen, NC. In this scheme described in preferences 4 & 5, nanofibers are created by melt blowing a fiber with a modular die. The fibers produced are a mixture of both micron and submicron sizes. This 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 cost less than $10 per kilogram. However, there are still several unknown and 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, certainly takes nanofibers production from a laboratory curiosity to a possible commercial future.

A third technique that can be used to produce nanofibers is spinning bicomponent fibers that split or dissolve. There are several approaches to using this technology to make nanofibers. The most researched approach is the production of islands-in-the-sea (INS) fibers (Figure 2) using a standard spin/draw process. 1120 islands were used and the composite fiber had a final drawn denier of one. The production rate was approximately 5 kilograms per hour at a take-up speed of 2500 mpm. PP,PET and PA-6 were all used for the island polymer with EVOH used as the sea polymer. The bicomponent polymer ratio was 50/50. The resulting nanofiber after dissolving the sea polymer had a diameter of approximately 300 nm. Unlike electrospinning and melt spinning, the nanofibers produced with this technique had a very narrow diameter range. The projected cost of these fibers is in the range of $1 to $5 per kilogram which should be low enough for most commercial applications particularly since most applications will include a small percentage of nanofibers combined with standard melt spun fibers.

Another possible approach to the use of bicomponent fiber spinning to manufacture nanofibers is to make splittable fibers in a melt spinning process (Ref. 6). The number of segments would need to be sixteen or greater and the best approach might be to use a water dissolvable polymer in a small ratio along with PET or PP (Figure 3). The ultimate approach is to melt blow INS fibers that contain > 600 island fibrils that would have diameters as low as 50 nm and which act as a regular melt blown fiber through fabric formation after which the sea polymer is dissolved and only the nanofibers are left.

Based on this review of the existing manufacturing processes for polymeric nanofibers, the potential to bring large quantities of nanofibers to the market place at relatively inexpensive prices appears feasible and can be achieved within the next five years. There is still a lot of development to be concluded and end uses must be proven; however, polymeric nanofibers do appear to be in the future of the fiber industry.

References:

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5 - U.S. Patent 6,114,017; "Micro-Denier Nonwoven Materials Made Using Modular Die Units", A. Fabbricante, G. Ward and T. Fabbricante, September 5, 2000.

6 - U.S. Patent 5,935,883; "Super Fine Microfiber Nonwoven Web", R. Pike, August 10, 1999.

Table I

Common Terms Used to Describe the Size of Fibers

Term Definition
Monofilament
A single filament of fiber used individually with a denier generally greater than 14 (Ref 1) The size of nanofibers are usually described by the diameter in either microns or inches (mils)

Denier Weight-per-unit-length measurement of a liner 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 10 microns.

Micron
(-Sized Fibers) When fiber size is less the 0.3 denier it is best to define the size is terms of its diameter in microns (10-6 meters)

Nanofibers Term used for fibers with diameters less than 0.5 microns. Typical nanofibers have a diameters between 50 and 300 nanometers. They can not be seen without visual amplification. (See Table II).
Other terms often used are micro-denier, sub-micron and superfine.

Key Dimensions in Nanometers

Atom - 0.3 nm

Polymeric Nanofiber - 50 to 500 nm

Melt Blown Fibers - 2,000 to 5,000 nm

Blood Cell - 5,000 nm

1.5 Denier Fiber - 12,500 nm

Human Hair - 20,000 to 30,000 nm

Figure 1

Schematic of the Electrospinning Process

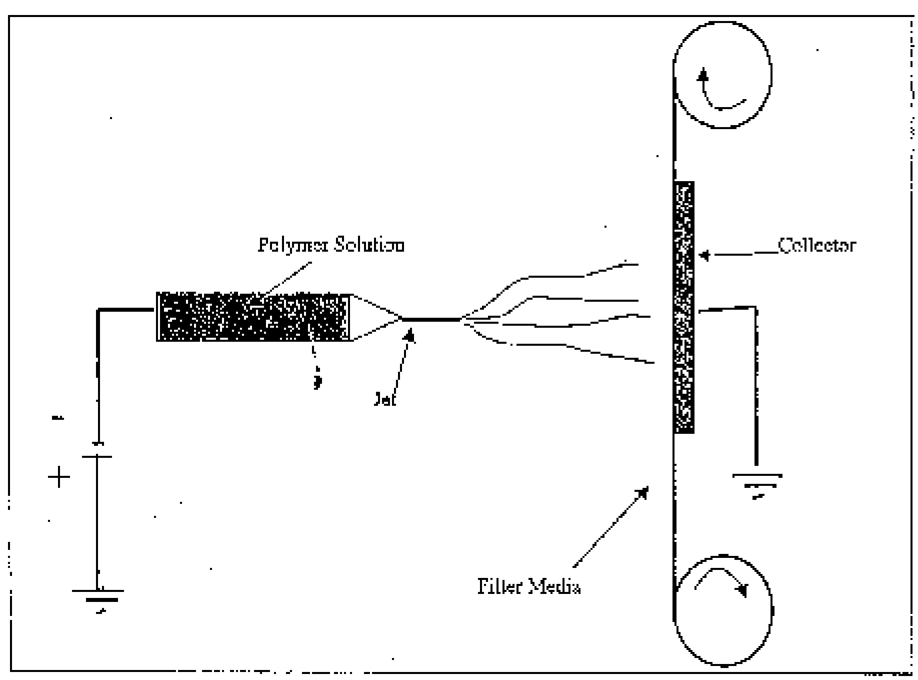

Figure 2

600 Islands-in-the-sea

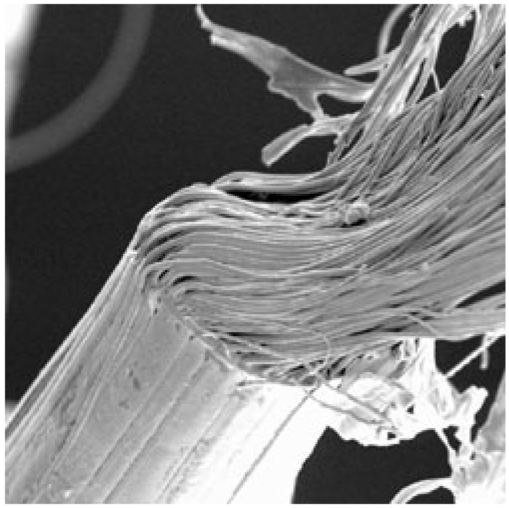

Figure 3

16 Segment Pie