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Editorial

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Advances in Polymeric Nanofiber Manufacturing Technologies

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Nanofibers continue to be one of the major success stories of nanotechnology. Whereas the definition of nanofibers according to National Science Foundation is that the diameters have to be less than 100nm, in the textile trade, fibers less than one micron in diameter are treated as nanofibers. It has been a challenge to produce fibers of less than one micron for a long time, and in major applications such as in filter media, submicron fibers, especially in the range of 500nm have been demonstrated to be more effective than fibers of less than 100nm.

Main advantage of polymeric nanofibers is their enormous specific surface area and high flexibility. As a result, webs consisting of submicron fibers have large surface-to-volume ratio, and porosity with both micro and nano pores. These nanofiber webs find numerous applications such as in in filter media, catalysis, super absorbents, as scaffolds for tissue engineering and wound dressings, for energy storage, and electronic applications. The nanofiber market worldwide is showing continuing growth trend, and with recent advances in the technologies, it should be possible to produce nanofibers at production rates orders of magnitude higher than that of conventional electrospinning [1].

Nanofibers definitely have a great benefit over the microfibers in filter media applications. Several industries such as food, pharmaceuticals, biotechnology etc., require highly pure air, water, gasses and chemicals that are free of any contaminants, hazardous biological agents and allergens. Nanofiber webs are also attractive for use as protective fabrics against environmental and infectious agents in hospitals, homes and offices. Filtration area will continue to be the largest application for nanofibers. Functionalized nanofibers are attractive as affinity membranes for removing heavy metals, which are challenging by conventional methods. If the cost of nanofibers goes down, other application areas in electronics, biotechnology and medical will also benefit. Because of the growth potential in both existing and emerging markets, there is continuing effort to produce nanofibers by various techniques, and also to investigate the potential techniques in more detail to make them a commercial success. The key techniques that have shown potential for success in the marketplace are briefly discussed.

Numerous techniques including super drawing, templating, phase separation, self-assembly, electrospinning, centrifugal spinning and melt blowing have been investigated as possible approaches to produce nanofibers from various polymers. Among these techniques, electrospinning has been the extensively investigated method [2]. Although far-reaching research has been conducted in the area of electrospinning, this technology is still struggling to grow beyond the laboratory scale. From the initial very slow single jet spinning, electrospinning has evolved into systems of multiple jets, and needleless spinning, both of which have allowed increase in production rates, compared to the earlier systems. Even with these advances, the fabrication rates are a lot lower for adaptation in production lines. Although electrospinning allows uniform production of submicron fibers, and fiber diameters smaller than 100nm under appropriate conditions, electrospinning has been slow in capturing large markets, and this can be attributed to issues related to high voltage, solvent handling, environmental safety, productivity, and production cost. Also, electrospinning is not suitable for polymers like polypropylene, which is widely used in filter media. However electrospinning with recent advances provides flexibility to fabricate complex parts with high precision and is expected to be a useful technique for high performance value added products required for many specialty applications [3].

Melt blowing process has been commercially successful and dominant to produce fine fibers in high-end filtration. In the normal melt blowing process, average diameters of the produced fibers are in the range of 2-5 microns. In the recent past, it has been demonstrated by our pilot line studies using modular dies; it is possible to produce submicron fibers from a wide range of polymers including polypropylene, polyesters and polylactic acid. The fiber diameters achieved in the modular melt blowing process ranged from 50 nm to 900 nm, with average values in the range of 400-600nm [4,5]. The advantage of submicron fibers for filtration related applications is that it is possible to achieve greater filtration efficiency keeping the pressure drop still low, resulting in higher filter quality factor [6]. Hence, modified meltblowing process is unique and innovative to produce submicron fibers in a cost effective manner at production rates and line speeds that are equivalent to those required at the industrial scale. However, this process is limited to thermoplastic polymers and availability of high melt blow rate resins is essential to achieve fine fibers.

Another promising technology is based on the well-known method of centrifugal spinning. Forcespinning® process developed and marketed by the company FiberRio has demonstrated the capability to handle both the melts and solutions to achieve submicron fibers at higher production rates. Average fiber diameters in the range of 100-400nm have been realized with a few different polymers [7]. Several other organizations around the world are trying variations of the centrifugal spinning process to produce nanofibers.

Specialty yarns consisting of microfibers have been produced for several decades using the bicomponent fiber spinning of two immiscible polymers. This produces a sea-island structure and the dissolution of the matrix leaves nanofibers. A recent development of this technology that has shown some promise uses the spunbond process, where multicomponent fibers are extruded and then by solvent separation nanofibers are produced [8]. With further

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developments in the die design, nanofibers with average diameters ranging from 50nm to 100nm can be achieved in this process. Since nanofibers useful for filter media can be produced at much higher production rates, this technology has potential for commercial success with additional research and development on optimizing polymer/process combinations and fiber splitting conditions.

Some of the other techniques being researched with optimism include magnetospinning and solution blow spinning. Magnetospinning utilizes the elongation of ferrofluid droplets using a magnetic field, and fiber diameters as small as 50nm have been demonstrated [9]. Unlike in electrospinning, the magnetospinning is not dependent on the dielectric constant of the system. There is need for a small amount of ferromagnetic additive, and it is claimed that the additive does not affect the mechanical properties. In the solution blow spinning a commercial air brush and compressed carbon dioxide are used to generate nanofiber mats [10]. This process, although has shown success in limited applications, requires a volatile solvent and high pressure gas source and has not attracted much attention.

Because of the growing market need for nanofibers, there is continuing effort to develop new techniques, as well as improving the currently used techniques for making submicron fibers from diverse polymers in an economical way at higher production rates. Depending on the application and the specific requirements, there is room for multiple technologies to evolve and grow. Techniques such as melt blowing or their variations with higher production rates and absence of solvents are more appealing for large scale commercial implementations.

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