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Polymeric Nanofibers: Recent Technology Advancements Stimulating their Growth

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Introduction

Nanotechnology has offered several novel products, which have superior properties making them valuable for a wide range of applications. One of the major successes of nanotechnology has been nanofibers. Although true definition of nanofibers is that the diameters have to be less than 100 nm, fibers less than a micron in diameter are considered as nanofibers in the textile industry. Polymeric nanofibers have enormous specific surface area and high flexibility. As a result, nanofiber webs have large surface-to-volume ratio, micropores, and high porosity, and hence find numerous applications such as in the domains of decontamination, catalysis, filtration, super absorbents, as scaffolds for tissue engineering and wound dressings, for energy storage, and many electronic applications. It is estimated that the current nanofiber market worldwide may be $400 million and will be worth more than $1 billion by 2020. This is likely to happen with recent advances in the technologies, as one can produce nanofibers at production rates, orders of magnitude higher than that of conventional electrospinning.

Nanofibers can be produced by a number of different techniques utilizing physical, chemical, thermal, and electrostatic fabrication techniques such as bacterial cellulose, super drawing, templating, phase separation, vapor-phase polymerization, self-assembly, kinetically controlled solution synthesis, electrospinning, novel modular meltblowing and centrifugal spinning. Of these techniques, electrospinning is the most extensively studied in the past two decades, and lately has made significant inroads into commercial products. Although extensive research has been done in electrospinning, it has taken a lot longer for this technology to grow beyond the laboratory scale. Whereas electrospinning has evolved from very slow single jet spinning to systems of multiple jets or needleless spinning, which has allowed increase in production rate, still the rates are much lower than what is desired for it to be economical. In spite of the fact that electrospinning allows uniform production of fine fibers, and under suitable conditions much smaller than 100 nm, because of issues related to solvent handling, high voltage, environmental and safety issues, productivity, accuracy and reproducibility at higher production rates, and cost of production, electrospun nanofibers have been very slow in capturing larger potential markets such as the filter media. Also, some of the polymers extensively used in filter media such as polypropylene do not have a suitable solvent for use in electrospinning.

One of the technologies that has been prominent in high-end filtration has been the melt blowing process to produce microfibers. In a typical melt blowing process average fiber diameters are in the range of 2-5 microns. In the past few years, it has been shown by our research working with several companies that using modular melt lowing process or special dies, it is possible to produce submicron fibers from various polymers such as polypropylene, polyesters and polylactic acid. The fiber diameters were in the range of 50 nm to 900 nm, with average diameters in the range of 400-600 nm [1]. With these fine fiber filter media it is possible to achieve higher filtration efficiency with lower pressure drop, leading to much better filter quality factor [2]. Hence, modular meltblowing is a unique and novel process to produce nanofibers in a cost effective way at high production rates and line speeds comparable to those desired at the industrial scale. With a minimum modification to existing production lines, it is possible to produce submicron fibers suitable for filter media using this technology.

Another technology that has been showing promise is based on the very old centrifugal spinning. Forcespinning® being developed and marketed by FiberRio has the capability to handle both the solutions and melts and produce submicron fibers at higher production rates. Fiber diameters in the range of 100-400 nm have been achieved with various polymers [3]. There are a few other variations of the centrifugal spinning being tried in pilot lines by other agencies.

Bicomponent fiber spinning with a sea-island structure of two immiscible fibers and then dissolving the matrix has been in use for making specialty yarns consisting of microdenier fibers. As a further development of this technology to use multicomponent fiber spinning in the spunbond process and then separating the nanofibers has a great promise [4]. With recent advances in the die design, several 100 to thousands of islands-in-the-sea fibers can be produced in melt spinning at fairly high production rates allowing nanofiber web production after splitting. Average fiber diameters in the range of 50nm to 100nm can be achieved in this process. As this process allows nanofiber production for filter media development at higher production rates and in a commercially feasible way, shows a better potential for commercial success with some additional research on optimizing the polymer combinations and splitting conditions.

Food, pharmaceuticals, biotechnology industries need a highly purified air, water, gasses and chemicals free of contaminants, hazardous biological agents, allergens and pollutants. Nanofibrous media definitely hold great advantage over the microfibers in filtration, and nanofiber webs can act as protective fabrics against environmental and infectious agents in hospitals, offices and homes. Whereas filtration segment will likely be the largest application for nanofibers, functionalized nanofibers will be used as affinity membranes for filtering heavy metals that are difficult by conventional purification methods. Other application areas in biotechnology, medical and electronics applications will also benefit from the availability of a variety of nanofiber webs at reduced cost. Whereas the newer technologies discussed above will increase their market share in filtration related applications, the ability to use many

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non thermoplastic polymers, and additives that are difficult to process in melt systems, with its ability to produce more uniform and much finer fibers will help growth of electrospun fibers in the specialty and functional fibers areas. Thus the prospects are much better than they have been in the past two decades and the large-scale commercialization will likely become a reality within the next five years.

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