Book Review: "Electrospinning of Micro- and Nanofibers: Fundamentals in Separation and Filtration Processes"

H. Young Chung, Ph.D.

Donaldson Co., Inc., Minneapolis, Minnesota, USA

Authors: Y. Filatov, A. Budyka, and V. Kirichenko
Karpov Institute of Physical Chemistry, Moscow
RUSSIA
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Electrospinning has been a subject of intense research during the last fifteen years. There have been several excellent monographs on this subject and numerous review articles. There also have been keen interest in commercialization of this technology, in part spurred by Donaldson's success in Ultra-Web® nanofiber products. However, it was not generally known that the former Soviet Union has quietly been conducting research on electrospinning and has made products for military and civil purposes. With the break-up of former Soviet Union, we came to know the extent of their research.

The book "Electrospinning of Micro- and Nanofibers; Fundamentals and Applications in Separation and Filtration Processes" by Y. Filatov, A. Budyka, and V. Kirichenko is devoted not only to the scientific aspects of electrospinning but to production of materials and their uses in practical terms. The book reflects scientific methodology developed at Karpov Institute of Physical Chemistry and includes results of more than 70 years of studies and learned expertise in electrospinning materials comprising micro- and nanofibers. Our hats are also off to Dr. Dmitry Luzhansky of Donaldson, who devoted considerable effort in translating the Russian text and editing the English language version of this milestone publication.

In Chapter One, the authors describe the mechanism of the electrospinning process and discuss equations governing the process parameters that control the spinning. They start out by saying the electrospinning process depends on process parameters that can produce droplets (electroatomization as it is in electrospraying process) or fibers (electrospinning). The authors show how one process becomes the other and propose the equation for calculation of stable jet flow. In the process of electrospinning, we can observe decrease of the fiber diameter up to $1x10^5$ times. That means that the fiber length will increase $1x10^{10}$ times. To resolve the issue of compacting such enormous amount of fiber, the authors propose a model of successive splitting of solution jets. Following such an approach, a theory based on fundamental and empirical equations was developed. The theory incorporates parameters of the process and spinning solution properties. This allows the calculation of process parameters and average fiber properties. The theory also helps researchers and engineers calculate process limits.

Chapter Two discusses raw materials that are used in electrospinning: polymers, solvents, solution properties, and additives to the solutions to tailor the properties in needed directions. The authors reviewed the properties of more than 25 polymers used in their research. This list of polymers includes anything from common polymers such cellulose derivates, PVC, PVA to exotic polymers like Polyarylide and Copolymer of Vinylidene Fluoride with Tetrafluoroethylene (called F-42). They also described 20 solvents used in solution preparation. A significant part of the chapter is devoted to the problem of spinnability. Each polymer is characterized from the standpoint of fibers that can be spun. Additives are used to change spinnability and modify wettabililty, polarity and other surface properties.

Chapter Three discusses effects of solution properties on fiber formation in an electrostatic field. Most of the attention is paid to such properties as concentration, viscosity, degree of polymerization and macromolecular factors.

Chapter Four focuses on the technology of electrospinning, process layout, and industrial equipment including injectors and spinning machines. Solution compositions and typical process parameters are described and discussed. This part could be emphasized as the quintessence of the

electrospinning process and probably will attract the most interest. The authors present two fundamental approaches to the electrospinning design: capillary based and non-capillary process systems. The theory of electrospinning defines variables that are governing the process. The big scale parameters can be divided in two groups – field, and heat- and mass transfer. The book delves into the volt-ampere characteristics of the process and its use in process control. Along with it air temperature, humidity, and air velocity in the chamber are controlled. The chapter describes emitters developed over the years and implemented in manufacturing. Described emitters can be classified as single-jet and multi-jet, blow and non-blow, capillary and non-capillary. Authors analyze their positive and negative sides. Thy also describe organization of the manufacturing process with use of multiple jets and non-capillary based systems. Depending on the system, the reader can find in this book the fundamental parameters that one would need to run a successful electrospinning operation. These include solvents, additives, needed electrical conductivity of the solution, minimum and maximum flow rates per capillary or emitting device, and amount of air needed to blow the solution. The chapter provides a simple formula that helps to estimate the radius of fibers in case of jet splitting and in case wet jet solidifies before splitting. All this information provides practically step-by-step instruction on how to build and successfully run the process of electrospinning for a wide range of polymer systems.

Chapter Five is devoted to the subject of capturing aerosol particles by fibrous filters. It describes aerosol formation, types of aerosols and particulates, plus theoretical fundamentals of filtration by fibrous filter media, including single fiber filtration efficiency. The authors describe in depth non-steady state filtration.

Filter materials produced in the USSR and in Russia nowadays by electrospinning have the general name "Petryanov Filters" (PF). Over the years, an enormous family of products has been developed and in Chapter Six, properties of many of these materials are reviewed, especially with regard to electric charge, mechanical properties, and filtration efficiencies. Presented are properties and performance data for over 50 different electrospun materials used in filtration. The chapter provides information on material and single fiber morphology and how this affects filtration. This is further supplemented with information on structural defects.

Construction and assortment of filters utilizing PF are presented in Chapter Seven. The chapter leads off with a description of methods of filter and filter materials' testing that are being used at Karpov Institute and in Soviet filter manufacturing. What attracts the most interest in Chapter Seven is the wide variety of modular, high efficiency filters developed over the years for protective purposes. Covered are characteristics of over 200 different kinds of filter media incorporating PF materials. These filters are classified into groups based on the impurities the filters were designed to effectively capture or remove. These impurities include radioactive, biologically and chemically toxic aerosols, atmospheric particulates and aerosols, particulate removal from non-atmospheric gases, etc.

The final Chapter Eight discusses a wide variety of applications where modular PF based filters are used. Gas flow rates in these applications may vary from 9 up to $9x10^6$ cubic feet per hour. The authors cite specific applications and show schematics of filtration systems using PF filter materials. Applications include practically all areas of industry.

Any monograph based on the history of a signature organizational effort reflects the approaches and biases of the group. This book is no exception. Some of the content differs from published work of recent American scientists. However, this is a good thing because it will undoubtedly spark rigorous scientific discussion. I am not comfortable with the cost of the book as it would be out of reach for most graduate students. Nevertheless, for researchers in the field, it is a publishing achievement and an extraordinary reference.

AUTHOR'S ADDRESS
H. Young Chung, Ph.D.
Donaldson Co., Inc.,
P.O. Box 1299
Minneapolis, MN 55440
USA
Email: h.chung@donaldson.com

Editor: We cordially invite you to share your thoughts on electrospinning and other associated subject areas. Please submit your comments, suggested additions, and letters to the editor at http://jeff.edmgr.com.