Wicking Phenomenon in Polyacrylonitrile Nanofiber Yarn

Mahbube Sadat Musavi Jad, Seyed Abdolkarim Hosseini Ravandi*, Hossein Tavanai, and Razieh Hashemi Sanatgar

Department of Textile Engineering, Nanotechnology & Advanced Materials Institute, Isfahan University of Technology, 84156 83111, Isfahan, Iran

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Abstract: The aim of this paper is to investigate vertical wicking in polyacrylonitrile (PAN) electrospinning nanofiber yarn using image analysis. Colored liquid rising phenomenon into the yarn and the distance of liquid rise were determined as a function of time. The kinetics of capillary rise follows the Lucas-Washburn equation. The results show that capillary rise rate coefficient is being reduced with increasing yarn twist, due to the reduction of continuity and size of capillaries. Increasing heat treatment stretch from 0 % (draw ratio=1) to 50 % (draw ratio=1.5) increases the capillary rise rate coefficient, due to the more homogeneity of capillary spaces in the yarn structure and increasing heat treatment stretch from 50 to 100 % (draw ratio=2) reduces capillary rise rate coefficient, because of the low capillary length. The present study indicates that an appropriate choice in production parameters of nanofiber yarn is all important in obtaining the desired properties of capillary rise.

Keywords: Nanofiber yarn, Wicking, Twist, Heat treatment stretch, Electrospinning

Introduction

Spontaneous movement of liquids in fibrous assemblies such as yarns is as a result of capillary forces acting on the liquid. The transport of a liquid into a fibrous assembly, such as yarn or fabric, may be caused by external forces or by capillary forces only. A spontaneous transport of a liquid driven into a porous system by capillary forces is termed "wicking". Capillary behavior is a function of the pore characteristics of yarns (namely dimensions and inter-connectivity), the fiber surface characteristic (e.g. contact angle) and liquid properties [1].

Proper dimension to produce sufficient capillary pressure is needed, while inter-connective pathways transport the liquid. The liquid is retained by overall porosity [2].

Capillaries are much better defined in continuous filament yarns under tension than in twisted staple yarns. The rate of travel of liquid is governed by the fiber arrangement factors in yarns which control capillary size and its continuity [3,4].

According to equation (1), the rate of height of liquid in fibrous structures as a result of capillary force is defined by:

$$\frac{dh}{dt} = \frac{r_e^2}{8\eta h}\left[\frac{2\gamma\cos\theta}{r_e} - \rho g h\right] \tag{1}$$

Where h is liquid height as a function of time t, r_e is equivalent radius of capillary porous structure, η is liquid viscosity, γ is surface energy, θ is contact angle between liquid and fibers and ρ is liquid density. Neglecting the hydrostatic pressure in the early stages of the wicking process ($h \ll h_{eq}$) integration of equation (1) leads to the well-known Lucas-Washburn's equation [1,5-7]:

$$h^2 = \frac{\gamma\cdot\cos\theta\cdot r_e}{2\eta}\cdot t \tag{2}$$

Equation (2) can be rewritten as:

$$h^2 = A\cdot t \tag{3}$$

Where

$$A = \frac{r_e\cdot\gamma\cdot\cos\theta}{2\eta} \tag{4}$$

The slope (A) is called the capillary rise rate coefficient.

Spontaneous liquid wicking capillary flow analysis is mainly applied to yarn structure. This analysis consists of measuring the time required for a liquid to wick into a certain length of yarn. Wicking time has been measured by several techniques. One of these methods consists of observing and measuring the capillary flow of a colored liquid, either when the yarn is placed perpendicularly to a liquid bath, or when a drop of liquid spreads on a yarn [1,5,6].

To apply Washburn's equation to wicking studies, numerous researchers established that the wicking height of liquid in a fiber or yarn is proportional to the square root of time, assuming that gravity is negligible as long as the wicking height is small [1,4,6-12]. However, the effect of gravity $-\rho gh$ cannot be neglected when the wicking height is great. For horizontal wicking and in the early stages of the vertical wicking, the effect of gravity is expected to be negligible. The Lucas-Washburn equation is often used to describe the capillary diffusion as can be seen in equation (3).

Electrospinning is a process for forming fibers with submicron diameters through the action of electrostatic forces. In typical process, an electrical potential is applied between a polymer solution or melt, exiting from a syringe

*Corresponding author: hoseinir@cc.iut.ir