Water Transport Models of Moisture Absorption and Sweat Discharge Yarns

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Water Transport Models of Moisture Absorption and Sweat Discharge Yarns *

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Abstract: An important property of moisture absorption and sweat discharge yarns is their water transport property. In the paper, two water transport models of moisture absorption and sweat discharge yarns were developed to investigate the influence factors on their wicking rate. In parallel Column Pores Model, wicking rate is determined by the equivalent capillary radius R and length of the capillary tube L. In Pellets Accumulation Model, wicking rate is decided by the capillary radius r and length of the fiber unit assemble L_0.

Key words *water transport; capillary action; parallel column pores model; pellets accumulation model; moisture absorption & sweat discharge yarn*

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Introduction

The water transport property is one of the key factors by which is influencing the comfort property of garments. Differential capillary effect fabrics were first developed by an American scientist.
Differential capillary effect fabrics were also developed in Japan, which were used to design famous sportswear, such as Adidas, Nike. The capillary action model was developed by Wang[1] to describe the influence factors. A kind of water transport model for knitted fabrics was developed by Meng[2]. In the mean time, wicking rate method and vertical water absorption method were optimized.

All the above researchers and scientists focus on fabric models and there are still few models on yarn. In this paper, two yarn models on water transport property were developed to investigate influence factors on wicking rate.

1 Parallel Column Pores Model

Capillary action is a physical effect caused by the interactions of a liquid with the walls of a thin tube. The capillary effect is a function of the ability of the liquid to wet a particular material[3].

The capillary effect was usually taken place in liquids, such as water (sweat is nearly a kind of water), which is ubiquitous and capable of strong surface interactions. Water climbs up a capillary tube because of the strong hydrogen-bonding interactions between the water and the air at the surface of the tube. The energetic gain from the new intermolecular interactions must be balanced against gravity, which attempts to pull the liquid back down. The narrower the diameter of a tube, the higher the liquid will climb; clearly, a narrow column of liquid weighs less than a thick one. The pressure in the capillary can be determined by Young-Laplace equation[4]:

$$P = \frac{2\sigma}{R}\cos\theta \qquad (1)$$

where, P is the pressure in the capillary (Pa); σ is the surface tension of the water (N/m); R is the equivalent capillary radius of fiber (m); θ is the contact angle at the liquid-solid-air interface (°).

When profiled fiber (i.e. the shape of the fiber cross section is like "+", "Y") was used to spin moisture absorption and sweat discharge yarn, the Parallel Column Pores Model can be adopted to describe the yarn structure, as shown in Fig. 1.

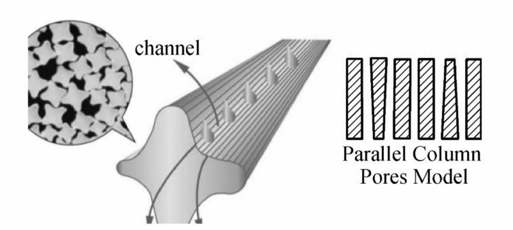

Fig 1 Profiled fiber and Parallel Column Pores Model

1.1 Conditions of capillary action

Assumption: the diameters of all tubes are the same; the water is a kind of distilled water; there is no

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temperature change and phase change during the transportation process.

According to the Young-Laplace equation, when the extra pressure on the capillary is greater than or equal to the gravity produced by the liquid in the capillary, the liquid will rise up and then capillary action happens. That is:

$$\frac{2\sigma\cos\theta}{r}\pi R^2 - \pi R^2 h\rho g \geq 0 \qquad (2)$$

where h, height of the capillary action (m); g, the acceleration of gravity (m/s^2); ρ, the liquid density (kg/m^3);

The height of the capillary action can be deduced from the Eq. (2)

$$h \leq \frac{2\sigma\cos\theta}{\rho g R} \qquad (3)$$

It can be seen from the Eq. (3) that when θ, s, and ρ are constants, h is decided only by the equivalent radius of the capillary R. Consequently, in order to find a kind of nice water transport property material, the equivalent radius of the fiber should be as small as possible.

1.2 Wicking rate

The height of capillary action per minute can be used to symbolize the wicking rate v (cm/min), and the wicking rate v is given as[5]:

$$v = \frac{h}{t} \qquad (4)$$

where, t is wicking time (min).

It is known that water is a kind of Newtonian fluid. Therefore, according to the Hagen-Poiseuille equation[6], the equation defines the flow through a tube and how this flow is affected by the attributes of the tube; the length and radius, and the attributes of the fluid; the viscosity. The Hagen-Poiseuille equation can be expressed as follows:

$$Q = k\frac{\pi R^4 P}{L} \qquad (5)$$

where, Q is the flow volume (L/s); k is a constant, which is related to the liquid viscosity η; L is the length of the capillary tube (m).

On the other hand, Eq. (5) can be also written as

$$Q = \frac{\pi R^4 P}{8\eta L} \qquad (6)$$

where, η is the liquid shear viscosity (Pa·s).

Substituting Eq. (1) into Eq. (6), the flow volume Q can be expressed, in principle, by the equation

$$Q = \frac{\pi R^3 \sigma\cos\theta}{4\eta L} \qquad (7)$$

As a result, wicking rate can be given by

$$v = \frac{dh}{dt} = \frac{Q}{\pi r^2} = \frac{R\sigma\cos\theta}{4\eta L} \qquad (8)$$

It can be seen from Eq. (8) that the wicking rate of the fiber assembles is decided by the length of the capillary tube L and the equivalent radius of the capillary tube R (when θ and σ are constants).

2 Pellets Accumulation Model

In Pellets Accumulation Model, it was assumed that the shapes of cross-section of all the fibers are circular and those fibers are tightly accumulated. The description of model is shown in Fig. 2.

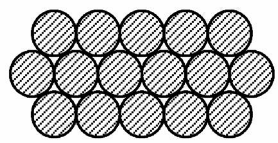

Fig 2 Pellets Accumulation Model

Single fiber unit model and fiber assemble unit model were developed. The two unit models are shown in Fig. 3 respectively.

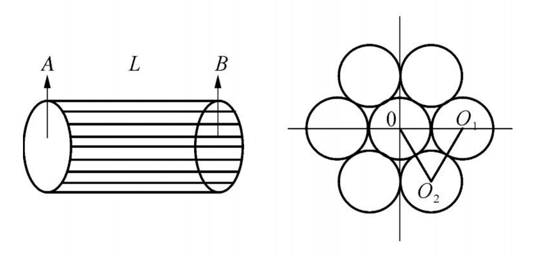

Fig 3 Single fiber unit model and fiber assemble unit model

Assumption: The fibers in fiber assemble unit model are parallel to each other and there is no yarn twist in fiber assemble model. In single fiber unit model, two centers of cross section A and B were chosen randomly, and linear distance of sides AB is L (m); the spaces among these fibers were seemed as capillary interspaces[7]; All the single fibers were rigid fibers, which insures the cross section shape of all the fibers cannot be changed when the fiber assemble was in a large stress. The pores among the fibers are the main tunnels to transport liquid water, and all the fibers are circular fibers and those fibers were arranged as shown in Fig. 3. It was assumed that the spacing sections among fibers are the same triangles. The radius of all the fibers is the same. It can be easily deduced that the number of triangles equals the number of fibers around one core fiber.

Each of the triangle area S can be defined as

$$S = \sqrt{3}r^2 - \frac{\pi}{2}r^2 \approx 0.16r^2 \qquad (9)$$

And the equivalent radius R of each triangle can be expressed as

$$R = \sqrt{\frac{S}{P}} \approx 0.057r \qquad (10)$$

The Pellets Accumulation Model can be seen as a kind of porous media, according to Darcy's Law[8],

$$q = -K \cdot \frac{P}{L_0} \tag{11}$$

where, q is the volume flux in the flow direction (m^3/min), P is the capillary pressure (Pa) and L_0 is the length of fiber unit assemble (m), K the proportionality constant, is the flow conductivity of the porous media with respect to the fluid. The higher the value of K, the lower the flow resistance of the fluid, and vice versa.

K is often defined as k/η, where k is the permeability of the medium, and η is the fluid viscosity. Then Eq. (11) can be written as

$$q = -\frac{k}{\eta} \cdot \frac{P}{L_0} \tag{12}$$

The wicking rate of the Pellets Accumulation Model can be expressed as

$$v = \frac{q}{S} \tag{13}$$

Then substituting Eq. (1), Eq. (9), Eq. (10) and Eq. (12) into Eq. (13), one can obtain

$$v = -219.3\,k \frac{\sigma \cos\theta}{\eta \cdot L_0 \cdot r^3} \tag{14}$$

It can be seen from Eq. (14) that when θ, S, k and η are constants (the same fiber and liquid), the wicking rate is determined by the length of fiber unit assemble L_0 and the capillary radius r.

Generally speaking, the permeability k can be measured by experimental and capillary radius r can be calculated. Consequently, different length of fibers unit assemble can be used to predict wicking rate of yarns.

3 Conclusions

In the paper, two water transport mathematical models of moisture absorption and sweat discharge yarns have been developed. The influence factors on wicking rate were also discussed. In parallel Column Pores Model, when the θ, ρ, s and g are constants, the wicking rate is decided by the equivalent capillary radius R and length of the capillary tube L. In Pellets Accumulation Model, when θ, s, k and η are constants, the wicking rate is determined by the capillary radius r and length of the fiber unit assemble L_0.

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References

[1] Wang Qi A Study of Moisture Absorption and Quick Dry Fabrics [D] Shanghai: Master's Thesis of Donghua University, 1995: 12 (in Chinese)

[2] Meng Jiaguang, Pan Jianjun Water Transmission Theory of Knitted Fabrics and Measurement [J] Textiles Science Research, 2005, **16**(3): 18-21 (in Chinese)

[3] Dan Berger, Madsci Network, What is Capillary Action? [OL] (1998-02-12) http://www madsci org/posts/archives/1998-02/887637827 Ch r html

[4] Gordonm Barrow Physical Chemistry (Fifth Edition) [M] New York: McGraw-Hill Book Company, 1988: 108

[5] Yu Weidong, Chu Caiyuan Textile Physics [M] Shanghai: Donghua University Press, 2002: 270-272 (in Chinese)

[6] Victor L Streeter, Fluid Mechanics (the 9th Edition) [M] Beijing: Tingshua University Press, 2003: 271

[7] Zhu Fangliang, Zhang Yan, Zhuang Yi, et al, Analysis on Wicking Effect of Profiled PTT Fibers [J] Synthetic Fiber Industry, 2006, **29**(3): 7-9 (in Chinese)

[8] Pronoy K ChatterJee Absorbency: Textile Science and Technology [M] New York: Elsevier, 1984: 36