Study on moisture absorption and sweat discharge of honeycomb polyester fiber

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Abstract. The moisture absorption and liberation properties of honeycomb polyester fiber were studied in order to understand its moisture absorption and sweat discharge. Through testing moisture absorption and liberation regains of honeycomb polyester fiber and normal polyester fiber in standard atmospheric conditions, their moisture absorption and liberation curves were depicted, and the regression equations of moisture regains to time during their reaching the balance of moisture absorption and moisture liberation were obtained according to the curves. Their moisture absorption and liberation rate curves were analyzed and the regression equations of the rates to time were obtained. The results shows that the moisture regain of honeycomb polyester fiber is much bigger than the normal polyester fiber’s, and the initial moisture absorption and moisture liberation rates of the former are much higher than the latter’s, so that the moisture absorbance and sweat discharge of honeycomb polyester fiber are excellent.

1. Introduction
With the continuous improvement of living standards, the functions and comfort of clothing have been paid more and more attention. The fabrics made from polyester fiber have good elasticity, wrinkle resistance, shape retention, excellent wash-and-wear performance and durability, and so on, so that it is widely used in all kinds of apparel fabrics. However, because polyester fiber is poor in moisture absorption, its clothing makes wearer to feel hot and sticky, produces static electricity easily which results in clothing absorbing dust and clinging to the body, and has poor comfort. Therefore, it is one of the research hotspots in man-made fiber and textile industry in recent years that hygroscopic polyester fiber is given the certain hydrophobic property. The polyester fibers with moisture absorption performance emerged as the times require under this kind of background [1].

In the early 1980’s, Teijin Company began to research and develop moisture absorption and perspiration polyester and produced the microporous hollow fiber. Coolmax fibers are functional made by DuPont Co R & D. They are not round, but are slightly oblong in cross-section with grooves running lengthwise along the threads. They are manufactured in either a tetrachannel or hexachannel style. The series of closely spaced channels creates capillary action that wicks moisture through the core and out to a wider area on the surface of the fabric which increases evaporation [2, 3]. Later, a lot of fiber producers in Taiwan have also developed a variety of moisture absorption and perspiration fibers, such as Technofine, Topcool and Coolplus [4]. Internationally, many fiber production

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enterprises and companies have developed a variety of moisture absorption and perspiration fibers, such as "Ekslive" (Toyobo Company), "Aerocool" (South Korean Hyosung Corp.), and "Wellkey-MA" (Teijin Company). A lot of moisture absorption and perspiration fibers with having good properties have been developed in China, such as Coolbst, Cooldry and Coolnice.

Honeycomb polyester fiber with microporous structures is developed through the methods of the chemical and physical modification by Shangyu Hongqiang color polyester Co. Ltd. in order to improve the handle, moisture permeability and dyeing property of polyester fiber. It is also called wicking fiber or breathing fiber. There are honeycomb microporous structures on its surface and in the interior (Figure 1), it is quick drying and fast in heat dissipation. Not only can it be dyed by cationic dyes under the conditions of normal temperature and pressure, but also its dyeing time is short and its dye-uptake is high, which can save energy and decrease the cost. The fiber is soft and fluffy like cotton and has good drape and air permeability is good, which improves the comfort of ordinary polyester fibers.

It can be widely used for underwear, sportswear, casual wear, athletic wear, T-Shirts, shirts, pants, sports wear, suit, dress, sock lining etc. [5], and will be used in other fields, such as home furnishing, agriculture, health care and other areas, especially in military uniform. The natural conditions of military training, exercises and combat are hard, especially in hot areas or summer, and sweat and heat will not only affect one’s health, but also may affect one’s mood, therefore if they wear the clothing of moisture absorption and sweat discharge, the problems would be solved or improved [5-7].

2. Experimental materials and methods

2.1. Materials
1.33 dtex honeycomb polyester fiber and 1.33 dtex normal polyester fiber from Shangyu Hongqiang Color Polyester Co. Ltd.

2.2. Principles and methods
2.2.1. Principles. The speed of fiber absorbing moisture or releasing moisture is indicated by the variation of the moisture regain of unit mass fiber under the standard atmospheric conditions as shown in (1) [8, 9]:

\[
v = \frac{dw}{dt}
\]

Where:
\(w\) = the moisture regain of fiber absorbing moisture or releasing moisture at any time,
\(t\) = the time for fiber absorbing moisture or releasing moisture.

The principle of the moisture absorption rate is in the same as the moisture desorption’s, but they are
opposite. Through the equation (1) for the integral operation is integral, the regression equation of moisture regain to time is:

\[ w = a + be^{-ct} \]  

Where: \(a, b, c\) = constant.

That is the curve of the moisture regain to time is an exponential curve during the process of the balance of fiber’s moisture absorption and desorption.

By the equation (1) is known, the regression equation of fiber moisture absorption rate and desorption rate is:

\[ v = -bce^{-ct} \]  

2.2.2. Apparatus. MP-200A electronic balance with the accuracy of 0.001 g from Yuhua Instrument Co. Ltd., Y802A eight basket oven (Changzhou Textile Instruments Factory), glass dishes, YG715B constant temperature and humidity box (Ningbo Textile Instruments Factory).

2.2.3. Conditioning and Methods. Tests are according to the national standard “GB6503-2008: Testing method for moisture regain of man-made fibers”.

Moisture absorption: the 1 g fiber is weighed after conditioning it for more than 24 h under standard atmosphere, 20±2°C and 65±5% relative humidity, and then put in the oven to dry at the temperature of 105°C for 1h and then weighed in the oven. Afterwards, the fiber is weighed once every 10 min. until it loses no more then 0.05% of its mass at 10 min. intervals to stop drying and the latter mass is as the fiber’s dry weight. The fiber (the sample of constant mass) is carried out of the oven and weighed quickly in the conditioning room. The mass is the initial one (G0). The fiber is put in the glass dish, and it is weighed once every 5 min and the mass (Gt) is recorded until it increases less than 0.05% of its mass at 5 min intervals. The moisture regain at every weighted time for the fiber is calculated for drawing the moisture regain curve. The calculation equation of the fiber’s moisture regain (Wt) is as follows:

\[ W = \left( W_t - W_0 \right) / W_0 \times 100\% \]  

Where: \(G_0\) = dry mass, \(G_t\) = fiber mass at the time t.

Moisture liberation: The 1 g fiber is weighed at the standard atmosphere and put in the constant temperature and humidity box of 20°C and 100% relative humidity for 96 h until the fiber researches moisture saturation. Then the fiber is removed out of the box and put quickly in the standard atmosphere. The measurement method is in the same as the moisture absorption’s. Finally, the fiber which has balanced is dried and weighed. The moisture regains at the time t is calculated and the moisture liberation curve is drawn.

3. Results and discussion

3.1. Moisture regains and liberation curves and discussion

3.1.1. Moisture regains and liberation curves. The curves drawn according to the results of the moisture regain of the honeycomb polyester and the normal polyester fiber are as shown in figures 2 and 3. It is known from figure 2 that the moisture regain of the honeycomb polyester fiber at the moment of the moisture absorption balance is much larger than the normal polyester fiber’s, respectively 1.19% and 0.21%, the former is 5.67 times of the latter. However, the moisture absorption rates of both fibers are similar in the trends. The fibers’ moisture absorption rates are relatively quick in the initial stage of their moisture absorption, but they slow down obviously with the increase of the moisture absorption time. The speed of the moisture absorption of the honeycomb polyester fiber has slowed at the time 25
min. to 40 min., but the normal polyester fiber’s has slowed at the time 10 min. to 25 min., afterwards their moisture absorption were gradually tends to balance.

Figure 2. Moisture absorption curves.

Figure 3. Moisture liberation curves.

The moisture regain of the honeycomb polyester fiber is much larger than the normal polyester fiber’s after they have been processed in the constant temperature and humidity box as shown in figure 3. The fibers released moisture quickly in the initial stage, but they do slowly with the extension of time. The moisture regains of two fibers are respectively 1.33% and 0.51% after they have been at the moisture liberation balance. The moisture regains of the fibers at the moisture absorption balance are higher than the corresponding ones at the moisture liberation balance, respectively 11.7% and 142.88%, which are caused by the hygroscopic hysteresis of the fibers [10]. However, the moisture regains of honeycomb polyester fiber at the moisture absorption balance and the moisture liberation balance are respectively higher of 466.67 and 160.78% than those of the normal polyester fiber.

3.1.2. Analysis of moister absorption and liberation. (1) Moister absorption and liberation: The capacity of the moisture absorption and desorption of fibers depends on their chemical and physical structures. The gaseous water from the skin surface evaporating is first absorbed by fibers and then released in the air through the fibers’ surfaces. The capillary effect caused by the microporous on the surfaces of honeycomb fibers and in them and the interspaces among them gap makes the liquid water from the skins be adsorbed by the fibers, diffuse and evaporate. These two kinds of interaction make the moisture and water migration. These properties are not only relative to the fiber surface charges and electrical property [11], but also relative to fiber’s specific surface area and internal voids. The larger the surface area of a fiber is, the more the number of molecules on its surface is, so its surface
energy is larger and its surface adsorption capability is stronger. Therefore the ability that the fiber surface adsorbs water molecules is stronger, and its moisture absorption is better [10].

The specific surface area of honeycomb polyester fiber with honeycomb microporous structure is 170 times that of cotton fiber, and its microporous are connective each other and with the atmosphere. So that its moisture absorption and desorption are better than theses of normal polyester fiber and it has capillary wicking effect and higher moisture regain.

(2) Moisture regains at the balances of moisture absorption and desorption: Because the fiber molecules and water molecules attract each other and bind when the fiber absorbs water, the kinetic energy of water molecules will reduce and convert into heat energy to be released so then the heat will be generated [10]. In the initial stage of moisture absorption, the steam pressure is high in the atmosphere, and water molecules enter into the fiber, which leads to the fiber moisture regain larger, at the same time, the temperature of the fiber increases because of the effect of moisture absorption and heat release. More molecules and higher temperature make the steam pressure of the fiber become larger gradually. When the steam pressure of the fiber is close to that of the air, the fiber is in the moment equilibrium of moisture absorption and stops absorbing moisture. However, the fiber will release moisture when the steam pressure of the fiber is larger than that of the air. When the heat generated by moisture-absorption quickly transfers to the air, the fiber will begin to absorb moisture until the steam pressure and temperature of the fiber are in the same as those in the atmospheric conditions when the fiber moisture absorption is in the state of equilibrium. Because the moisture and temperature in the fiber change its steam pressure, its moisture regain can fluctuate. When the fiber is dry, its steam pressure is low because there is little moisture in it, so that its moisture regain does not fluctuate in the initial stage of moisture absorption. This is because though initially a little moisture enters into the fiber to cause its temperature higher, but it is not enough to make the steam pressure of the fiber in the same as that in the air [12]. The principles of the fiber’s moisture absorption and desorption are same, but their processes are opposite.

The balanced moisture regains of the moisture absorption and desorption of honeycomb polyester fiber fluctuate very slightly, but the normal polyester fiber’s do not basically as shown in figures 2 and 3. Because the moisture regain of the former fiber is larger than that of the latter fiber, the steam pressure of the former fiber would have some change, but the steam pressure of the latter fiber would not have any change basically.

3.2. Establishment of regression equations of moisture regains and rates of moisture absorption and liberation of two fibers

The rates of the moisture absorption and liberation of the fiber during the processes are always in change. When the results were done curve fitting, the regression equations of the moisture regains of two fibers’s moisture absorption and liberation to time have been obtained as shown in table 1. Also, the curves of their regression equations have been obtained as shown in figures 4 and 5.

The rate equations and curves of two fibers’ moisture absorption and liberation have been obtained by using the origin75 software to analyze the data, such as shown in table 2 and figure 6. The rates of two fiber’s moisture absorption and liberation with time decreased exponentially.

| Sample                  | Moisture absorption     | Moisture liberation    |
|-------------------------|-------------------------|------------------------|
| Honeycomb polyester fiber | \( w = 0.01189 - 0.01183e^{-0.28623r} \) | \( w = 0.01328 + 0.00882e^{-0.0913r} \) |
| Normal polyester fiber  | \( w = 0.0021 - 0.00209e^{-0.03025r} \) | \( w = 0.00512 + 0.00454e^{-0.13285r} \) |
In the initial stage of moisture absorption, the moisture absorption rate of the honeycomb polyester fiber is faster, but the rate rapidly decreases with the time. The absorption rate from 10 min. is obviously slow and is gradually approaching the moisture absorption rate of the normal polyester fiber. The curves of the moisture absorption rates of two fibers after 20 min. begin to coincide and gradually trend to 0, which the moisture absorption of two fibers is in the state of balance. In the stage of moisture liberation, the moisture liberation rate of the honeycomb polyester fiber is faster than that of normal polyester fiber, but they have a similar trend. Two fibers’ rates from 10 min. are obviously slow, but the rate of the former is obviously faster than that of the latter. The curves of the moisture liberation rates of two fibers from 30 min. begin to coincide and gradually trend to 0, which the moisture liberation of two fibers is in the state of balance. Therefore, the honeycomb polyester fiber has excellent moisture absorption and desorption performance.

**Table 2.** Regression equations of rates of fibers’ moisture absorption and liberation to time.

| Sample                  | Moisture absorption           | Moisture liberation         |
|-------------------------|-------------------------------|-----------------------------|
| Honeycomb polyester fiber | $w=0.00339e^{-0.28623t}$ | $w=0.00081e^{-0.0913t}$ |
| Normal polyester fiber   | $w=0.00063e^{-0.30258t}$   | $w=0.0006e^{-0.13285t}$   |
4. Conclusions
The honeycomb polyester fiber has excellent moisture absorption and liberation. Its initial moisture absorption and liberation rates are much faster than those of the normal polyester fiber. The garments made of the honeycomb polyester fiber can absorb the sweat from human bodies and have good moisture wicking properties. There are a lot of microspore connected each other on the surface of honeycomb polyester fiber and in it, which increases its specific surface area. The moisture regain of the fiber is much higher than that of the normal polyester fiber, which is in favor of textile processing and increases the comfort of garments.

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