EXPERIMENTAL AND THEORETICAL INVESTIGATION OF DRYING KINETICS OF COTTON BOBBINS

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Abstract
In this study, the drying behavior of cotton bobbins was simulated by empirical and semi-empirical drying models available in the literature. For this aim, firstly, experimental drying behavior of cotton bobbins was determined on an experimental bobbin dryer setup which was designed and manufactured based on hot-air bobbin dryers used in textile industry. Then, drying models considered were fitted to the experimental data. The fit was performed by selecting the values of coefficients in the models in such a way that these values make the sum of the squared differences between the experimental and the model results for moisture ratio minimum. Suitability of fitting was specified as comparing the correlation coefficient, standard error and mean square deviation. Results show that the most appropriate model in describing the drying curves of cotton yarn bobbins is the Page model. The results also show that temperature have a significant effect on drying.
Key words: Drying, Cotton, Bobbin, Modeling

1. Introduction

Drying is one of the most important and most frequently applied unit operations in a large variety of industrial applications. In textile industry drying is a time-consuming, energy-intensive and expensive process and constitutes one of the major cost elements among the textile finishing operations. Convective hot-air drying is usually encountered in many industrial applications such as textile, food, pharmaceutics and forest.

Considerable studies on the investigation of heat and mass transfer processes and diffusion mechanisms in textile fibers are present in literature [1-5] and some of them are concerned with textile bobbins. For example in a study Ribierio and Ventura (1995) reported on an experimental investigation to study drying of wool bobbins by hot air [6]. In a theoretical study performed by Akyol et al. (2010) an inverse heat transfer problem was solved in order to determine effective thermophysical properties of a wool bobbin exposed to convective drying [7]. Lee et al. (2002) developed a transient two dimensional mathematical model to simulate the through-air drying process for tufted textile materials [8]. Li and Zhu (2003) studied an improved model of liquid water transfer coupled with moisture and heat transfer in porous textiles by analyzing the physical model of liquid diffusion in porous textiles [9].

The aim of this study is to simulate drying behavior of cotton bobbins by empirical and semi-empirical drying models available in the literature.

2. Materials and Methods

The experiments were conducted in a pressurized hot-air bobbin dryer as shown in Fig.1. Ambient air was directed to an electrical heater with the maximum power of 25 kW by a centrifugal fan and the air pressure was supplied by a compressor with a nominal power of 15 kW. Air temperature was controlled proportionally. After the heater, air enters to a bobbin carrier system where the bobbins are dried. The carrier consists of four parts and two bobbins can be placed at each part. So totally, 8 bobbins can be placed in the carrier. In the carrier hot air is passed from inside to the outside of bobbins in radial direction. After carrier, drying air firstly enters to a cooling exchanger. The purpose of this process is to reduce relative humidity of the air. Afterwards, drying air enters to a separator. In the separator, water droplets hanging on the air are separated from the air. Drying air finally returns to the fan. The carrier has been placed on a loadcell in the experimental setup. The weights of the bobbins can be measured continuously by means of this loadcell with an accuracy of ±1g. The conditions of air at different points in the carrier and weights of the bobbins can be monitored by a software program, and the process can be controlled by an automatic control system in the experimental setup.

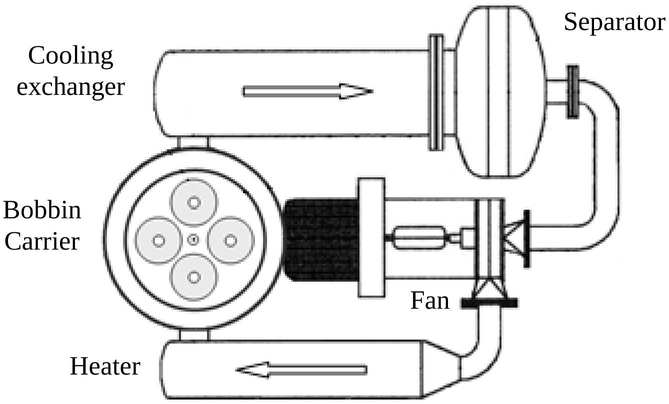

Figure 1. Schematic view of the experimental bobbin dryer

The experiments were carried out with samples of totally 8 cotton bobbins with hollow cylindrical shapes with the dimensions of 155 mm bobbin height, 33 mm inner radius and 90 mm outer radius. The dry weight of one cotton bobbin was approximately 1100±50g. The bobbins were dried with air at 70°C, 80°C and 90°C temperatures at a constant 2 bar effective pressure.

3. Mathematical Formulation

Four different empirical or semi empirical drying models given in Table 1 have been taken into account for determining the most appropriate model for the drying simulation cotton yarn bobbins.

Table 1. Drying models

Name	**Model equation**	**References**
Page [10]	$mr = \exp(-kt^n)$	Page (1949)
Henderson and Pabis [11]	$mr = a\exp(-kt)$	Henderson and Pabis (1969)
Geometric [12]	$mr = at^{-n}$	Cihan et al. (2007)
Wang and Singh [13]	$mr = 1 + at + bt^2$	Wang and Singh (1978)

mr in the drying models is the moisture ratio defined as:

$$mr = \frac{m - m_e}{m_o - m_e} \quad (1)$$

Here m, m_o m_e are the instantaneous, initial and equilibrium moisture contents, respectively. The coefficient of correlation (r) is one of the primary criteria for selecting the best equation. In addition to correlation coefficient, standard deviation (e_s) and mean squared deviation (χ^2)

are used to determine suitability of the fit. These parameters are defined as follows (Chapra and Canale, 1989) [14]:

$$r = \frac{n_o \sum_{i=1}^{n_o} mr_{pre,i} mr_{exp,i} - \sum_{i=1}^{n_o} mr_{pre,i} \sum_{i=1}^{n_o} mr_{exp,i}}{\sqrt{n_o \sum_{i=1}^{n_o} (mr_{pre,i})^2 - \left(\sum_{i=1}^{n_o} mr_{pre,i} \right)^2} \sqrt{n_o \sum_{i=1}^{n_o} (mr_{exp,i})^2 - \left(\sum_{i=1}^{n_o} mr_{exp,i} \right)^2}} \tag{2}$$

$$e_s = \sqrt{\frac{\sum_{i=1}^{n_o} (mr_{pre,i} - mr_{exp,i})^2}{n_o}} \tag{3}$$

$$\chi^2 = \frac{\sum_{i=1}^{n_o} (mr_{pre,i} - mr_{exp,i})^2}{n_o - n_c} \tag{4}$$

where $mr_{pre,i}$ is the ith predicted moisture ratio, $mr_{exp,i}$ is the ith experimental moisture ratio, n_o is the number of observations and n_c is the number of constants in drying model.

4. Results and Discussion

Curve fitting computations were carried on the 4 drying models given in Table 1 relating the drying time and moisture ratio. The results for the drying temperatures taken into consideration are given in Tables 2-4. Experiments were carried out for drying temperatures of 70, 80 and 90°C, effective pressure of 2 bar and a modest air velocity. The acceptability of the drying model is based on a value for the correlation coefficient r, which should be close to 1, and low values for the standard error e_s and the mean squared deviation χ^2. The results show that the most appropriate model in describing the drying curves of cotton yarn bobbins is the Page model, with a minimum r of 0.9891, with a maximum e_s of 4.14×10^{-2}, and with a maximum χ^2 of 1.71×10^{-3}. Henderson and Pabis and Wang and Singh models are other acceptable models. Among the models considered here, the geometric model appears to be the worst fit.

Table 2. Fit results for drying temperature T=70°C.

Model	Coefficients	r	e_s	χ^2
Page	k=0.79, n=0.85	0.9932	3.06×10^{-2}	1.08×10^{-3}
Hend. and Pabis	k=0.68, a=0.93	0.9321	3.28×10^{-2}	1.24×10^{-3}
Geometric	a=0.34, n=0.10	0.7484	1.74×10^{-1}	3.49×10^{-2}
Wang and Singh	a=-0.57, b=0.09	0.9846	5.96×10^{-2}	4.10×10^{-3}

Table 3. Fit results for drying temperature T=80°C.

Model	Coefficients	r	e_s	χ^2
Page	k=0.83, n=0.83	0.9894	3.80×10^{-2}	1.71×10^{-3}
Hend. and Pabis	k=0.72, a=0.93	0.9882	3.98×10^{-2}	1.87×10^{-3}
Geometric	a=0.35, n=0.10	0.7643	1.67×10^{-1}	3.30×10^{-2}
Wang and Singh	a=-0.62 b=0.11	0.9806	6.33×10^{-2}	4.74×10^{-3}

Table 4. Fit results for drying temperature T=90°C.

Model	Coefficients	r	e_s	χ^2
Page	k=0.93, n=0.94	0.9891	4.14×10^{-2}	2.10×10^{-3}
Hend. and Pabis	k=0.88, a=0.96	0.9895	4.06×10^{-2}	2.01×10^{-3}
Geometric	a=0.35, n=0.10	0.7622	1.80×10^{-1}	3.95×10^{-2}
Wang and Singh	a=-0.71, b=0.14	0.9863	5.40×10^{-2}	3.56×10^{-3}

The drying curves based on the Page model are shown in Figs. 2-4 along with the experimental moisture ratios. As it can be seen from the figures, moisture removal is fast at the beginning of the drying process, and the drying rate slows down considerably as the drying proceeds. As it can also be observed from the figures, the temperature of drying air has a significant effect on the drying rate.

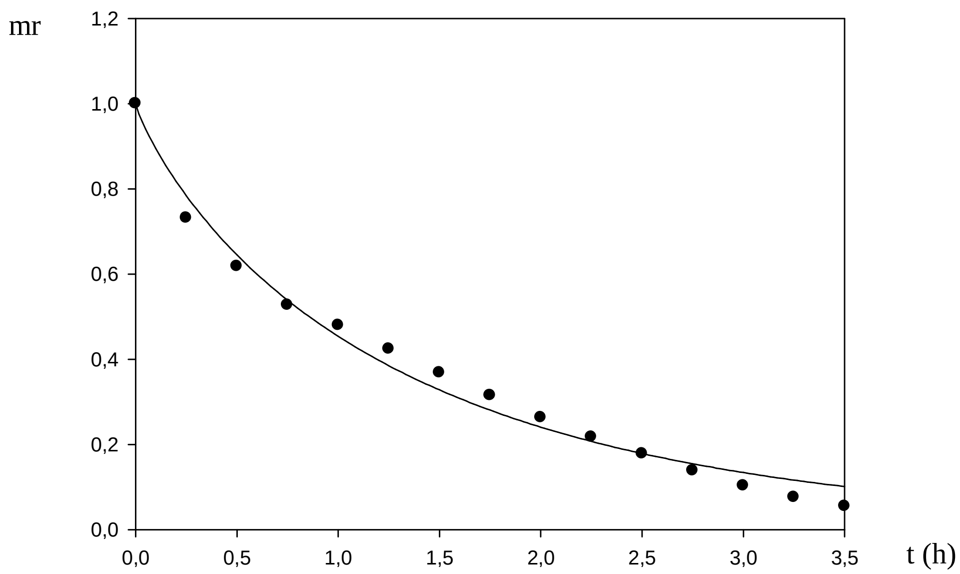

Figure 2. Drying curve for drying temperature T=70°C.

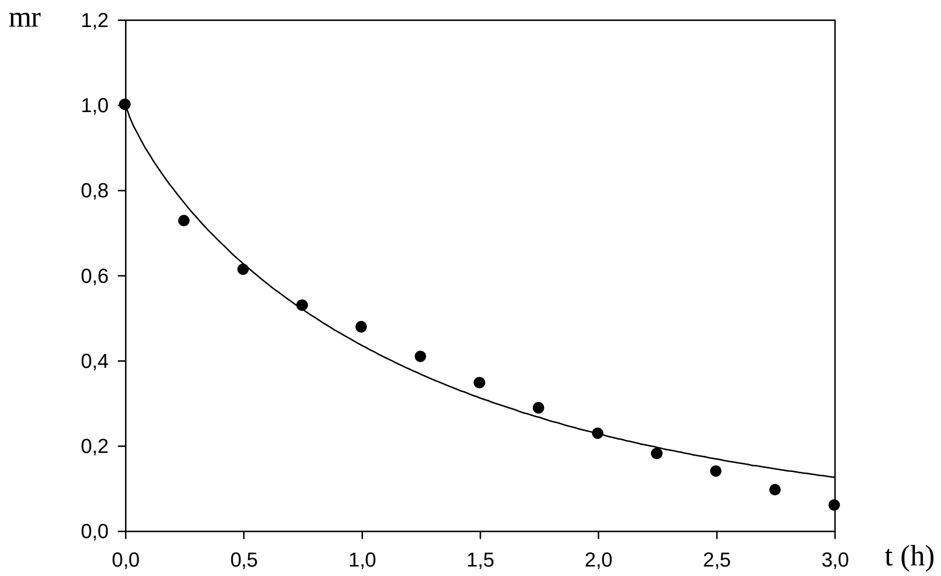

Figure 3. Drying curve for drying temperature T=80°C.

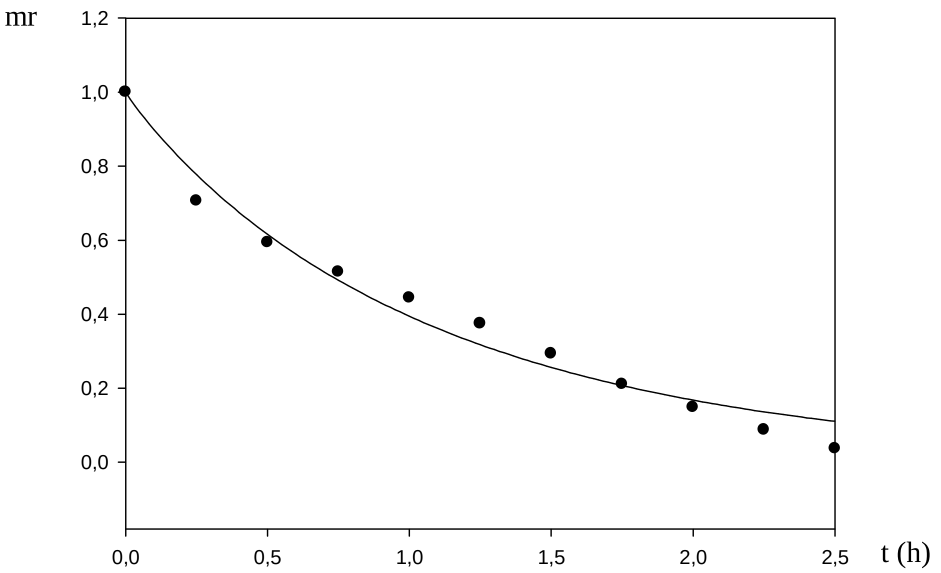

Figure 4. Drying curve for drying temperature T=90°C.

5. Conclusion

In this study, the drying behavior of cotton bobbins was simulated by empirical and semi-empirical drying models available in the literature using the experimental data. The results show that the most appropriate model in describing the drying curves of cotton yarn bobbins is the Page model, with a minimum r of 0.9891, with a maximum e_s of $4.14x10^{-2}$, and with a maximum χ^2 of $1.71x10^{-3}$. The results also show that the drying temperature has a significant effect on the drying rate.

Acknowledgement

The authors acknowledge the support received from TÜBİTAK.

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