International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:5, No:6, 2011

Investigation of Drying Kinetics of Viscose Yarn Bobbins

Ugur Akyol, Dinçer Akal, Ahmet Cihan, and Kamil Kahveci

Abstract**—**This study is concerned with the investigation of the suitability of several empirical and semi-empirical drying models available in the literature to define drying behavior of viscose yarn bobbins. For this purpose, firstly, experimental drying behaviour of viscose bobbins was determined on an experimental dryer setup which was designed and manufactured based on hot-air bobbin dryers used in textile industry. Afterwards, drying models considered were fitted to the experimentally obtained moisture ratios. Drying parameters were drying temperature and bobbin diameter. The fit was performed by selecting the values for constants 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. The results show that the most appropriate model in describing the drying curves of viscose bobbins is the Page model.

Keywords**—**Drying, moisture ratio, Page model, viscose

I. INTRODUCTION

DRYING is one of the oldest and most common unit operations found in diverse processes such as those used in the agricultural, ceramic, chemical, food, pharmaceutical, pulp and paper, mineral, polymer, and textile industries [1]. Drying techniques may be classified as mechanical or thermal. Mechanical processes are used in general to remove the mechanically entrained water by mechanical forces before drying with heat energy. After pre-drying, depending on their forms, textiles can be dried by several methods such as convective drying, contact drying, infrared or radiofrequency drying [2].

Inevitable after most dyeing or/and finishing processes, drying constitutes one of the major cost elements among the textile finishing operations. Convective drying process widely used in the textile industry consists of passing a hot air stream over the surface of the material to be dried. Air flow transfers heat to the material by forced convection, and at the same time, carries away evaporated water. The process continues until equilibrium is attained, depending upon drying air temperature and humidity. In this study a prototype convective air dryer was used to obtain drying behaviour of viscose yarn bobbins. Drying temperature and bobbin diameter were drying parameters. Then, various drying models have been considered to obtain a suitable model defining the drying behaviour of viscose based yarn bobbins.

Considerable studies on the investigation of heat and mass transfer processes and diffusion mechanisms in textile fibres are present in literature [3-7] 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 [8]. 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 process [9]. Lee et al. (2002) developed a transient two dimensional mathematical model to simulate the through-air drying process for tufted textile materials [10].

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

II. MATERIAL AND METHOD

The experimental hot-air textile bobbin dryer shown schematically in Fig. 1 basically consists of a centrifugal fan, an electrical heater, a bobbin carrier, a heat exchanger and a separator. The drying process in the experimental setup takes place as follows: Firstly ambient air is supplied to the dryer in a specified air pressure by an air compressor. The drying air in the system is directed to electrical heater by a centrifugal fan. Rotation speed of the fan and correspondingly the flow rate of the drying air can be adjusted with a frequency adjustable inverter. Volumetric flow rate of the drying air can be monitored by a flow meter placed at the outlet of the fan. The heater has the maximum power of 25 kW. The temperature of the drying air is controlled proportionally by a programmable logic controller (PLC). After the heater, air enters to a bobbin carrier system where the bobbins are placed in and dried. This carrier consists of four parts and four bobbins can be placed at each part. So totally, 16 bobbins can be placed in the carrier. In order to reduce the heat losses both surfaces of the heater and the bobbin carrier were insulated with glass wool. In the carrier, direction of drying air inside bobbins can be changed by a flap mechanism. This mechanism allows adjusting the flow direction of the drying air through the bobbins. After the bobbin carrier, drying air firstly enters to a shell-tube type

Ugur Akyol is with the Mechanical Engineering Department, Faculty of Çorlu Engineering, Namik Kemal University, Çorlu, Tekirdag, Turkey (e-mail: uakyol@nku.edu.tr).

Dinçer Akal is with Lüleburgaz Vocational College, Kırklareli University, Lüleburgaz, Kırklareli, Turkey (e-mail: dincerakal@trakya.edu.tr).

Ahmet Cihan is with the Mechanical Engineering Department, Faculty of Engineering and Architecture, Trakya University, Edirne, Turkey (e-mail: acihan@trakya.edu.tr).

Kamil Kahveci is with the Mechanical Engineering Department, Faculty of Engineering and Architecture, Trakya University, Edirne, Turkey (phone: +90-284-2261217; fax:+90-284-2261225; e-mail: kamilk@trakya.edu.tr).

heat exchanger. The moisture in drying air condenses on the surface of this heat 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 load-cell. Weights of the bobbins can be measured continuously by means of this load-cell. The conditions of air at different points in bobbin dryer and weights of the bobbins can be monitored by a software program, and the process can be controlled by PLC in the experimental setup.

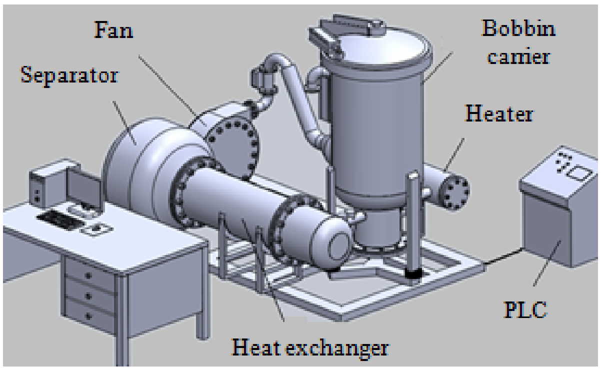

Fig. 1 General view of the experimental bobbin dryer

Viscose yarn bobbins have been used in the experimental study. Yarn has been wrapped to the plastic conics in the standard dimensions. Schematic view and geometrical dimensions for the bobbins used in the experiments have been shown in Figure 2 and Table I respectively. The experimental study has been carried out for an effective drying pressure of P_{eff}=2bar and a volumetric flow rate of Q=55m^3/h per bobbin.

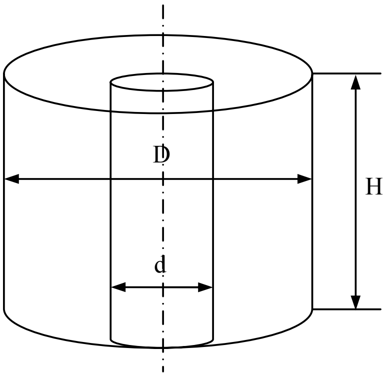

Fig. 2 Bobbin geometry

TABLE I
DIMENSIONS OF THE BOBBINS

H (cm)	d (cm)	D (cm)
15.5	5.4	10
		14

III. ANALYSIS

Due to the complexity of transport mechanisms empirical and semi-empirical models are often used to describe the drying behaviour of materials. The empirical and semi-empirical models require small time compared to theoretical models and do not need assumptions of geometry of the material, its mass diffusivity and conductivity and etc. Therefore they are useful for automatic control processes. Empirical and semi-empirical models are valid within the temperature, relative humidity, air flow velocity and moisture content range for which they were developed. Four different empirical or semi empirical drying models given in Table II have been taken into account to determine the most appropriate model for the drying simulation of viscose yarn bobbins.

TABLE II
DRYING MODELS

Name	Model equation	Reference
Page	$mr = \exp(-kt^n)$	[11]
Henderson and Pabis	$mr = a\exp(-kt)$	[12]
Geometric	$mr = at^{-n}$	[13]
Wang and Singh	$mr = 1 + at + bt^2$	[14]

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

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

Here m, m_o and m_e are the instantaneous, initial and equilibrium moisture contents, respectively.

IV. RESULTS AND CONCLUSION

Curve fitting computations were carried on the four drying models given in Table II relating the drying time and moisture ratio. The results are shown in Table III. The acceptability of the drying model has been based on a value for the determination coefficient R^2 which should be close to one and low values for the standard error EES and root of mean squared error RMSE. According to this evaluation, the most suitable model in describing drying process of drying behaviour of viscose yarn bobbin is the Page model.

The drying curves based on the Page model are presented along with the experimental data in Fig. 3 and Fig. 4. As it can be seen in the graphs, the temperature has a significant effect on drying, and as the temperature increases drying rate goes up considerably. High temperature decreases the relative humidity of the drying air and therefore drying potential increases. This is the main reason behind the effect of temperature on drying. As it can also be seen from the figures that total drying time increases 45 min for T=70°C, 30min for

T=80°C and 15 min for T=90°C with an increase of bobbin outer diameter from 10cm to 14cm. With an increase of drying temperature, the effect of bobbin diameter on drying time decreases as the temperature is a significant parameter on drying. It can also be seen from the figures that the Page model may simulate the drying behaviour of viscose yarn bobbins considerably well.

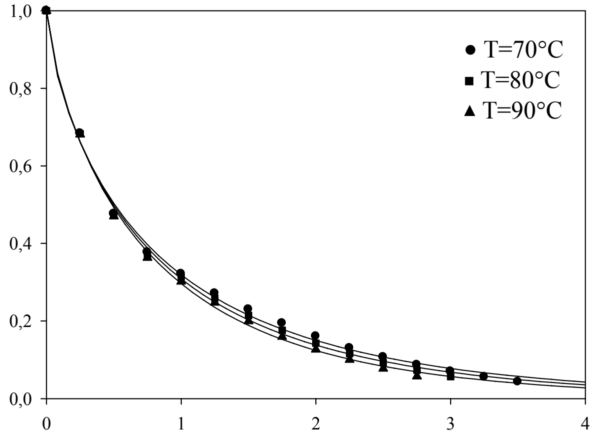

Fig. 3 Drying curves based on the Page model for D=10cm

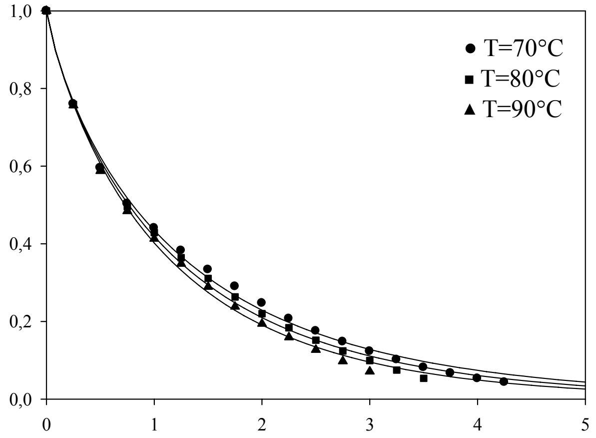

Fig. 4 Drying curves based on the Page model for D=14cm

TABLE III
RESULTS OF STATISTICAL ANALYSIS

Model	D (cm)	T (°C)	Coefficients	R^2	SSE	RMSE
Page	10	70	k=1.141, n=0.733	0.997	0.003	0.014
		80	k=1.175, n=0.753	0.998	0.002	0.013
		90	k=1.216, n=0.779	0.998	0.002	0.013
	14	70	k=0.834, n=0.821	0.997	0.004	0.016
		80	k=0.871, n=0.842	0.997	0.003	0.015
		90	k=0.911, n=0.863	0.998	0.002	0.014
Henderson and Pabis	10	70	a=0.920, k=0.999	0.978	0.025	0.044
		80	a=0.933, k=1.069	0.982	0.019	0.042
		90	a=0.945, k=1.138	0.986	0.014	0.038
	14	70	a=0.932, k=0.709	0.990	0.013	0.028
		80	a=0.946, k=0.773	0.992	0.009	0.026
		90	a=0.958, k=0.836	0.994	0.006	0.023
Geometric	10	70	a=0.249, n=0.165	0.697	0.304	0.153
		80	a=0.262, n=0.159	0.708	0.267	0.156
		90	a=0.264, n=0.157	0.711	0.255	0.160
	14	70	a=0.295, n=0.148	0.592	0.498	0.176
		80	a=0.313, n=0.140	0.608	0.413	0.178
		90	a=0.327, n=0.135	0.621	0.355	0.180
Wang and Singh	10	70	a=-0.741, b=0.142	0.931	0.119	0.096
		80	a=-0.826, b=0.181	0.945	0.080	0.085
		90	a=-0.883, b=0.207	0.954	0.062	0.079
	14	70	a=-0.558, b=0.083	0.964	0.080	0.071
		80	a=-0.630, b=0.108	0.971	0.050	0.062
		90	a=-0.696, b=0.135	0.978	0.032	0.054

ACKNOWLEDGMENT

The authors acknowledge the financial support received from TÜBİTAK.

REFERENCES

[1] A.S. Mujumdar, “Handbook of Industrial Drying”, vol. 1, Marcel Dekker, 1995.

[2] A. Cay, I. Tarakçıoğlu, A. Hepbasli, “Exergetic Performance Assessment of a Stenter System in a Textile Finishing Mill”, *International Journal of Energy Research*, vol. 31, pp. 1251-1265, 2007.

[3] Y. Li, Q. Zhu, K.W. Yeung, “Influence of Thickness and Porosity on Coupled Heat and Liquid Moisture Transfer in Porous Textiles”, *Textile Research Journal*, vol. 72, pp. 435-446, 2002.

[4] J.P. Fohr, D. Couton, G. Treguier, “Dynamic Heat and Water Transfer through Layered Fabrics”, *Textile Research Journal*, vol. 72, pp. 1-12, 2002.

[5] Y. Li, L. Zhoungxuan, “An Improved Mathematical Simulation of the Coupled Diffusion of Moisture and Heat in Wool Fabric”, *Textile Research Journal*, vol. 69, pp. 760-768, 1999.

[6] P.W. Gibson, M. Charmchi, “Modeling Convection/Diffusion Processes in Porous Textiles with Inclusion of Humidity-Dependent Air Permeability”, *International Communications in Heat and Mass Transfer*, vol. 24, pp. 709-724, 1997.

[7] Y. Li, Q. Zhu, “A Model of Coupled Liquid Moisture and Heat Transfer in Porous Textiles with Consideration of Gravity”, *Numerical Heat Transfer, Part A,* vol. 43, pp. 501-523, 2003.

[8] J. Ribeiro, J.M.P. Ventura, “Evaluation of Textile Bobbins Drying Processes: Experimental and Modeling Studies”, *Drying Technology,* vol. 13, pp. 239-265, 1995.

[9] U. Akyol, A. Cihan, R. Shaliyev, “Thermophysical Parameter Estimation of a Wool Bobbin during Convective Drying Process”, *Inverse Problems in Science and Engineering,* vol. 18, pp. 227-240, 2010.

[10] H.S. Lee, W.W. Carr, H.W. Beckham, J. Leisen, “A Model of Through Air Drying of Tufted Textile Materials”, *International Journal of Heat and Mass Transfer,* vol. 45, pp. 357-366, 2002.

[11] A. Cihan, K. Kahveci, O. Hacıhafızoğlu, “Modelling of intermittent drying of thin layer rough rice” *Journal of Food Engineering* , vol. 79, pp. 293-298, 2007.

[12] S. M. Henderson, S. Pabis, “Grain drying theory I, temperature effect on drying coefficient, *Journal of Agricultural Engineering Research*, vol. 6, pp. 169-174, 1961.

[13] G. Page, “Factors influencing the maximum rates of air-drying shelled corn in thin layers”, *MS Dissertation*, Purdue University, 1949.

[14] C. Y. Wang, R. P. Singh, “A thin layer drying equation for rough rice”, *ASAE Paper* No. 78-300, St. Joseph MI. USA, 1978.