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Experimental investigation on industrial drying process of cotton yarn bobbins: energy consumption and drying time

Giovanni Galoppi[a]*, Lorenzo Ferrari[b], Giovanni Ferrara[a], Ennio Antonio Carnevale[a]

[a] *Department of Industrial Engineering, University of Florence, Via di Santa Marta 3, 50139, Florence, Italy*
[b] *Department of Energy, Systems, Territory and Construction Engineering, University of Pisa, Largo Lucio Lazzarino, 1 – 56122, Pisa, Italy*

Abstract

In the textile industry, the drying process is a time consuming and energy expensive operation that influences strongly the cost of the textile finishing operations. For this reason, the study of innovative techniques plays a key role to decrease the energy consumption, the costs and the environmental impact. After a first mechanical process, the moisture is removed from yarn fibers by a thermal convection dryer that delivers hot air through the material. In this study, the drying process of cotton yarn bobbins is experimentally analyzed. With this aim, an experimental test rig was developed based on the geometry of industrial dryers. The influence of the drying air path and the air working conditions was assessed by performing tests with different configurations, temperatures and pressures. The results were analyzed in terms of drying time and energy consumption as the optimum drying condition is a trade-off between these parameters.

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Keywords: drying; experimental tests; cotton bobbin; energy consumption; air conditions influence

1. Introduction

The drying process is one of the most important and crucial operation in several industrial applications [1]. In the textile industry, drying is the stage between dyeing process and the last finishing treatments and requires high amounts

* Corresponding author. Tel.: +39-0574-831226.
E-mail address: giovanni.galoppi@unifi.it

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Nomenclature

Latin letters		*Greek letters*	
cp	Specific heat [kJ/kgK]	η	Efficiency
D	External diameter [m]		
d	Internal diameter [m]	*Subscritps*	
E	Energy consumption [kWh]	D	Dried
H	Height [m]	fan	Fan
h	Enthalpy [kJ/kg]	$heat$	Heater
$\dot{m}$	Mass flow rate [kg/s]	in	Inlet
R_t	Moisture content	is	Isentropic
T	Temperature [°C]	out	Outlet
t	Drying time [s]	W	Wet
W	Weight [kg]		

of energy. In particular, it uses up to 80% of all the energy consumed in the production of textile materials [2] and represents one of the major cost issues among the textile finishing operations. For these reasons, the drying time and the energy consumed must be taken into consideration in order to produce a dried product at minimum cost [3].

Drying of textile yarns consists of two successive operations: a mechanical and a thermal one. Mechanical processes are used to remove the water that is mechanically bound to the fiber and, in general, are based on centrifugal extraction. After the pre-drying, the remaining part of the water is removed by a thermal drying. This process can be performed in several ways, such as convective, contact, infrared or radiofrequency drying [4]. The most widely used drying technique is the convective one that consists of passing a hot air stream through the material to be dried. Heat is transferred from air to the material by forced convection and the evaporated water is carried out.

Since 80's, the research interest on the drying process has grown exponentially. In the literature, there are many investigations on the heat and mass transfer mechanisms in textile fibers with both numerical and experimental approaches. Lee et al. [5] developed a transient two-dimensional mathematical model to simulate the through-air drying process for tufted textile materials showing a closely agreement with experimental results. Li and Zhu [6] developed a model of liquid water, moisture and heat transfer in porous textiles that resulted in good agreement with experimental measurements. The drying process of layered fabrics was modeled by Fohr et al. [7] that found two formulations to estimate the hygroscopic character as function of the diffusion coefficient. Hamdaoui et al. [8] analyzed experimentally the thermal drying of knitted textile fabric at different temperatures and demonstrated that the drying phenomenon follows a polynomial law.

Among the studies on the textile drying, only a few of them dealt with textile bobbins. Akyol et al. [9] determined the thermo-physical properties of a wool yarn bobbin during a convective drying by using an inverse method. In the study of Ribeiro and Ventura [10], who reported an experimental investigation of wool bobbins drying by hot pressurized air, the temperatures in the bobbin were plotted to show the presence of an evaporation front. Akyol et al. [11] evaluated the influence of the thermodynamic conditions on the drying of wool bobbin showing the significant impact of the air pressure and that the process can be described with a logarithmic model. The optimum operating conditions were determined by Akyol et al. [12], who showed the influence of the drying temperature, pressure and mass flow rate on the drying time and the energy consumption. In a more extended work [13], the analyses were performed for different bobbin diameters and it was found a numerical model suitable to simulate the drying behavior.

In this work, the optimum drying conditions of cotton yarn bobbins in a dryer based on a typical industrial configuration were analyzed experimentally. Following the necessity of the textile industries of optimizing the drying process in terms of production costs, the authors performed experimental analyses at different temperatures, pressures and air paths. Before the thermal drying, the mechanical drying was performed with an innovative technique by creating a pressure difference between the external and internal side of the bobbins, which causes a wringing of the bobbins and a significant removal of water. The test rig was designed to perform both mechanical and thermal drying. A measurement system was developed to acquire the main parameters during the drying process. The results showed the influence of the drying conditions on drying time and energy consumption and an optimum solution was found.