# EFFECT OF DRYING AIR PRESSURE ON COTTON BOBBIN DRYING PROCESS

Ugur Akyol[1], Kamil Kahveci[2] and Ahmet Cihan[2]

[1] Department of Mechanical Engineering, Çorlu Faculty of Engineering,

Namik Kemal University, 59860 Çorlu, Tekirdag, Turkey

[2]Department of Mechanical Engineering, Faculty of Engineering and Architecture,

Trakya University, 22180 Edirne, Turkey

**Abstract**

*In this work, the drying behavior of cotton bobbins for different bobbin diameters and drying air pressures at a constant drying air temperature was simulated by empirical and semi-empirical drying models available in the literature. For this purpose 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 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 root of mean squared error (RMSE). The results show that the most appropriate model in describing the drying curves of cotton bobbins is the Page model. The results also show that both the bobbin diameter and the drying air pressure have significant effects on drying.*

**Key words:** *drying, cotton, bobbin, textile*

## 1. INTRODUCTION

Drying is widely used in a variety of applications ranging from food drying to wood drying. The drying industry uses large amounts of energy as drying is a highly energy-intensive operation [1]. Textile bobbins are passed through several processes such as dyeing and drying before they become market ready products. The purpose of drying is to remove the water inside the bobbins. Thermal dryers are sometimes used for pre-drying, but are almost always used for final drying because of the limitations of mechanical dryers. After mechanical pre-drying, much of the remaining water is chemically bonded to the fiber and must be evaporated. This is accomplished using several types of thermal system such as heated cans, convection ovens, and radio frequency dryers. Convection dryers are the most common type of dryers used for drying textiles and carpets. The drying medium is usually hot air though steam can be used if the temperature can be raised sufficiently high without damaging the textile [2]. Drying is a time consuming, energy intensive and expensive process and constitutes one of the major cost elements among the finishing operations in textile industry. Hence it is very important to determine effects of drying conditions on drying rates in such systems.

In the literature, many studies on textile drying have been undertaken by various researchers and some of them are concerned with textile bobbins. For example in a in a theoretical study performed by Akyol et al. [3] an inverse heat transfer problem was solved in order to determine effective thermophysical properties of a wool bobbin exposed to convective drying. In an experimental study performed by Cihan et al. [4] drying behavior of polyester based bobbins was simulated for different drying air temperatures by a simultaneous heat and mass transfer model by incorporating the physical mechanism of diffusion. Ribierio and Ventura [5] reported on an experimental investigation to study drying of wool bobbins by hot air. Lee et al. [6] developed a transient two dimensional mathematical model to simulate the through-air drying process for tufted textile materials. Li and Zhu [7] 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. Akyol et al. [8] determined the optimum operating conditions in convective drying process of viscose yarn bobbins experimentally. The results showed that total drying time was strongly dependent on drying pressure, drying temperature and volumetric flow rate and increase at these parameters shortened the drying time considerably.

In this study an experimental bobbin dryer has been used to investigate the effect of drying air pressure on cotton bobbin drying process. The tests were performed for three different bobbin diameters (D=10, 14, and 18 cm) and three different effective drying air pressures ($P_{eff}$=1, 2 and 3 bar) at a constant T=90$^{o}$C drying air temperature and a constant volumetric flow rate (Q=55m$^3$/h per bobbin).

## 2. MATERIAL AND METHODS

The experiments were carried out with samples of totally 8 cotton bobbins with hollow cylindrical shapes. The bobbins were dried with air at a constant 90°C drying air temperature for three different effective drying air pressures of 1, 2 and 3 bars. 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. After the heater, air enters to a bobbin carrier system where the bobbins are dried. The carrier consists of four parts and three 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 load-cell 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.

Before the drying experiments all bobbins were kept in a water bath during 12 hours to absorb the water fully, and then kept on a grill for 30 minutes to drain dripping water. Moreover, before the thermal drying operation, a pre-drying operation by passing the pressurized air through the bobbins without heating has been performed for 5 min duration before each thermal drying test to remove initial surplus water inside bobbins. Afterwards, cotton bobbins were placed inside the carrier and the experiments were performed in specified drying conditions.

## 3 MATHEMATICAL FORMULATION

Six 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 of cotton bobbins.

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.

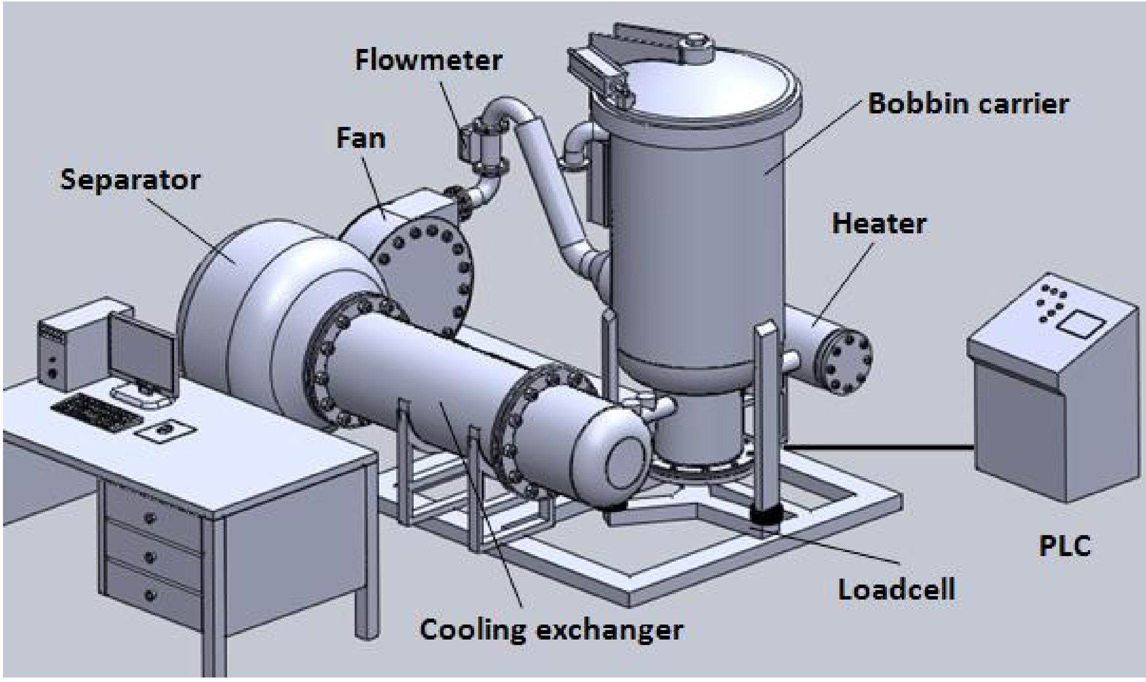


**Fig. 1**. Schematic view of the experimental bobbin dryer

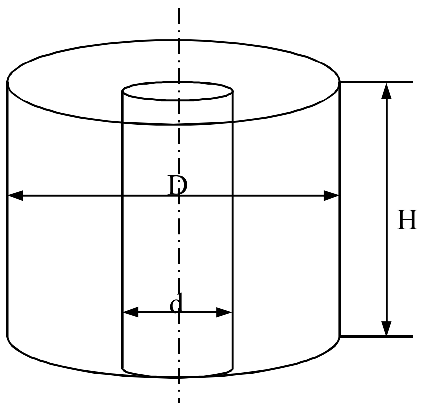


**Fig.2.**Bobbin geometry

Empirical and semi-empirical models are valid within the temperature, relative humidity, air flow velocity and moisture content range for which they were developed.

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

$$mr = \frac{m - m_e}{m_o - m_e} \tag{1}$$

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

## 4 RESULTS AND DISCUSSION

Curve fitting computations were carried on the 6 drying models given in Table 1 relating the drying time and moisture ratio. The acceptability of the drying model has been based on a value for the root of mean squared error RMSE which should be close to zero. According to this evaluation, the most suitable model in describing drying process of drying behavior of cotton yarn bobbin is the Page model. Table 2 shows the fit results for the Page Model for different bobbin diameters and different drying air pressures at a constant drying temperature (T=90°C) and a volumetric flow rate (Q=55m$^3$/h per bobbin).

Figures 3-11 show drying behavior of cotton bobbins at different air pressures for different bobbin diameters at a constant drying air temperature of T=90°C. In these figures, the dots indicate the experimental results while the straight lines indicate the Page model curves fitted to these results.

**Table 1.** Drying models

| Name | Model Equations | References |
|---|---|---|
| Page [9] | $mr=\exp(-kt^n)$ | Page (1949) |
| Henderson and Pabis [10] | $mr=a\exp(-kt)$ | Henderson and Pabis (1969) |
| Geometric [11] | $mr=at^{-n}$ | Cihan et al. (2007) |
| Wang and Singh [12] | $mr=1+at+bt^2$ | Wang and Singh (1978) |
| Logarithmic [13] | $mr=a_0+a\exp(-kt)$ | Kahveci K. and Cihan A. (2008) |
| Two term exponential [14] | $mr=a\exp(-kt)+(1-a)\exp(-kat)$ | Sharaf—Eldeen et al. (1980) |

**Table 2.** Fit results for different bobbin diameters and drying air pressures at T=90°C for Q=55 m$^3$/h

| T (°C) | D (cm) | $P_{eff}$ (bar) | k | n | RMSE |
|---|---|---|---|---|---|
| 90 | 10 | 1 | 1.454 | 0.749 | 0.012 |
| | | 2 | 1.522 | 0.716 | 0.015 |
| | | 3 | 1.494 | 0.770 | 0.012 |
| | 14 | 1 | 1.150 | 0.812 | 0.020 |
| | | 2 | 1.231 | 0.777 | 0.027 |
| | | 3 | 1.193 | 0.844 | 0.023 |
| | 18 | 1 | 0.829 | 0.970 | 0.036 |
| | | 2 | 0.927 | 0.939 | 0.049 |
| | | 3 | 0.872 | 1.014 | 0.038 |

As shown in Figures 3-5, drying takes 165 min at $P_{eff}$=1bar, 120 min at $P_{eff}$=2bar and 150 min at $P_{eff}$=3 bar for the bobbin diameter of D=10 cm. Similarly, according to Figures 6-8, the drying process ends at the 180th, 135th and 165th minutes at drying air pressures of 1 bar, 2 bar and 3 bar respectively for the bobbin diameter of D=14 cm. For a bobbin diameter of D=18 cm, the drying times are also; 195 min, 150 min and 180 min for $P_{eff}$=1, 2 and 3 bar respectively (Figures 9-11). It can be obviously seen that $P_{eff}$=2bar is the optimum drying air pressure value for the drying process in terms of the drying time due to the reasons discussed below.

The drying rate increases significantly as a result of the increase at the pressure. Specific humidity of ambient air has a certain value. Relative humidity of the drying air increases with the increase at air pressure at a constant specific humidity for a specific temperature of the drying air. This creates a negative effect on drying rate. Enthalpy of the drying air passing through bobbins in the bobbin carrier can be assumed to be constant. Therefore, air keeps track of the constant enthalpy curve on the psychometric chart while passing through bobbins. The difference between specific humidities across constant enthalpy curve decreases with the increase at the drying pressure. This also creates an adverse effect on drying rate. However, mass of the air increases as a result of the increase at the air pressure and this case causes a positive effect on drying rate. Increase at the pressure also leads to an increase at saturation temperature. Drying air enters to the condenser after the bobbin carrier. The higher difference between the temperatures of the cooling water circulating in the condenser and the air leaving the bobbin carrier causes higher decrease at relative humidity at the condenser. This provides more efficient moisture transfer. As a result of all at these effects, drying rate shows an increasing trend firstly and then a decreasing trend with the increase of the drying pressure.

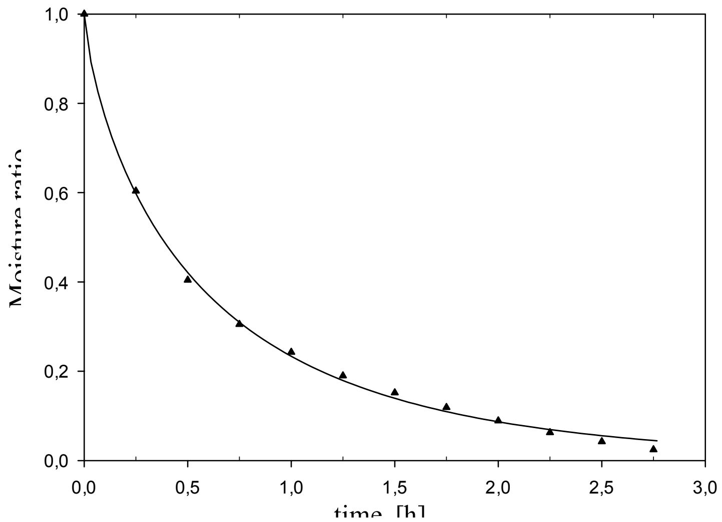


**Fig.3.** Drying behavior of cotton bobbins at $P_{eff}$=1 bar for D=10 cm

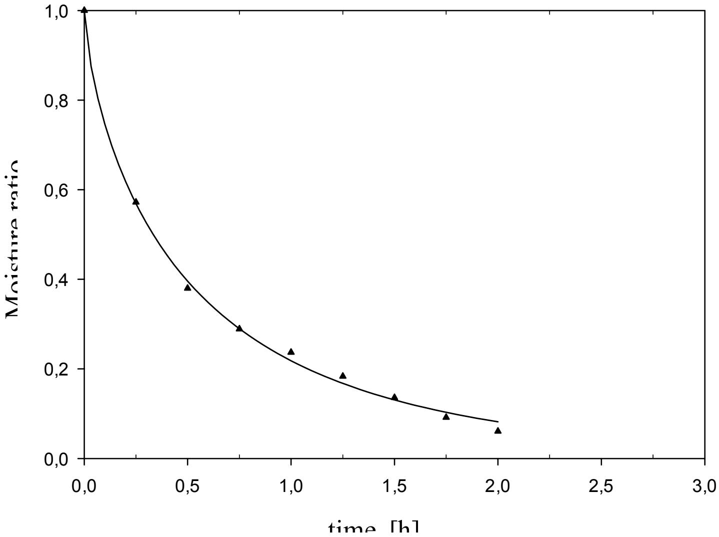


**Fig.4.** Drying behavior of cotton bobbins at $P_{eff}$=2 bar for D=10 cm

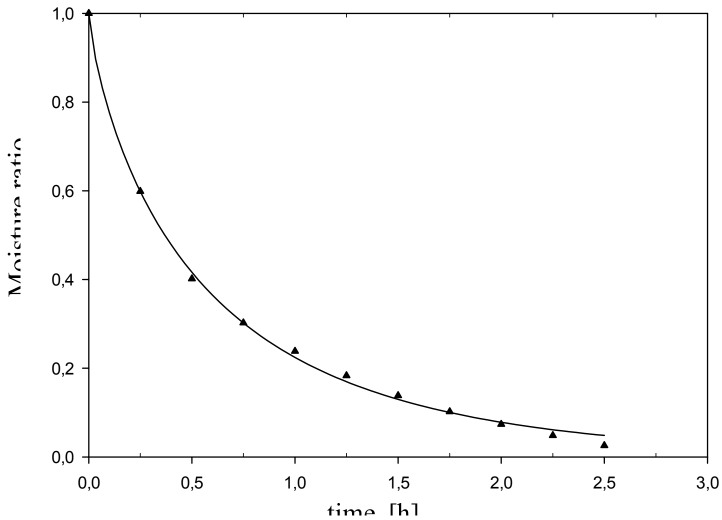


**Fig.5.** Drying behavior of cotton bobbins at $P_{eff}$=3 bar for D=10 cm

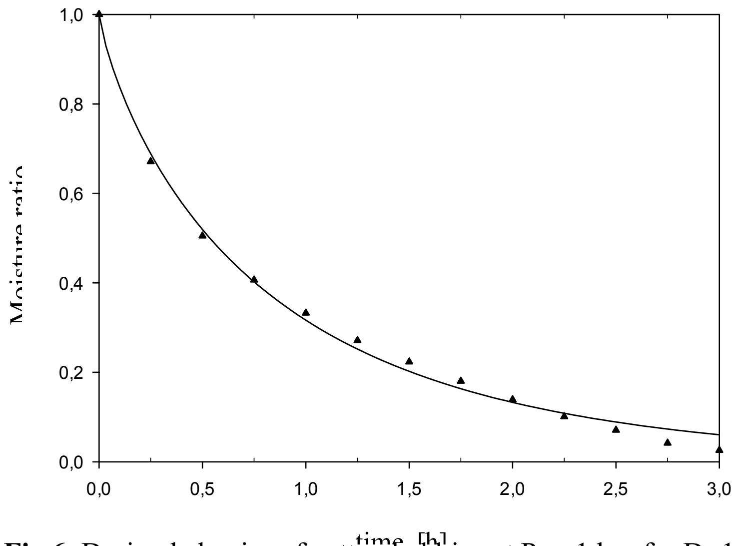


**Fig.6.** Drying behavior of cotton bobbins at $P_{eff}$=1 bar for D=14 cm

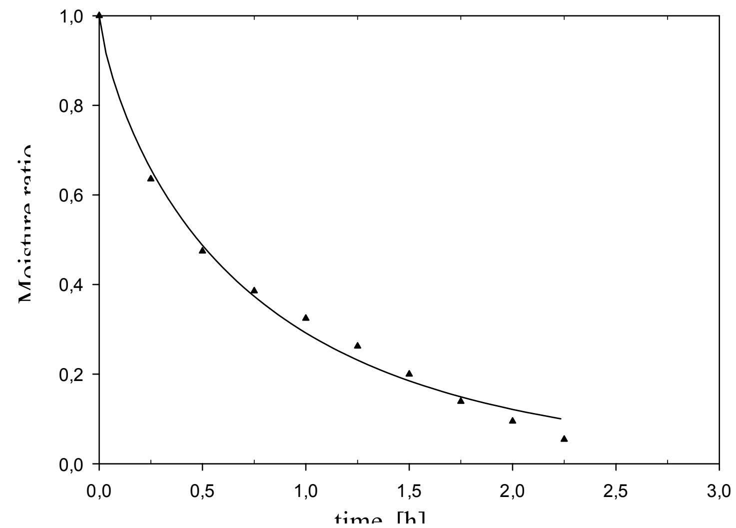


**Fig.7.** Drying behavior of cotton bobbins at $P_{eff}$=2 bar for D=14 cm

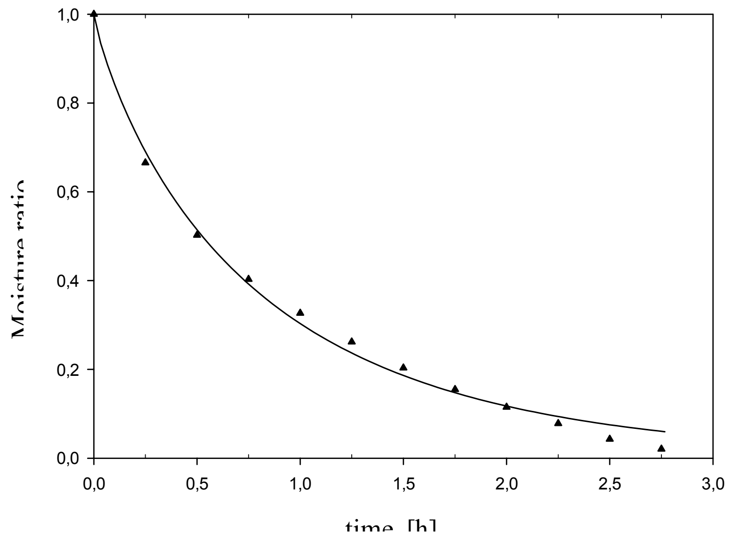


**Fig.8.** Drying behavior of cotton bobbins at $P_{eff}$=3 bar for D=14 cm

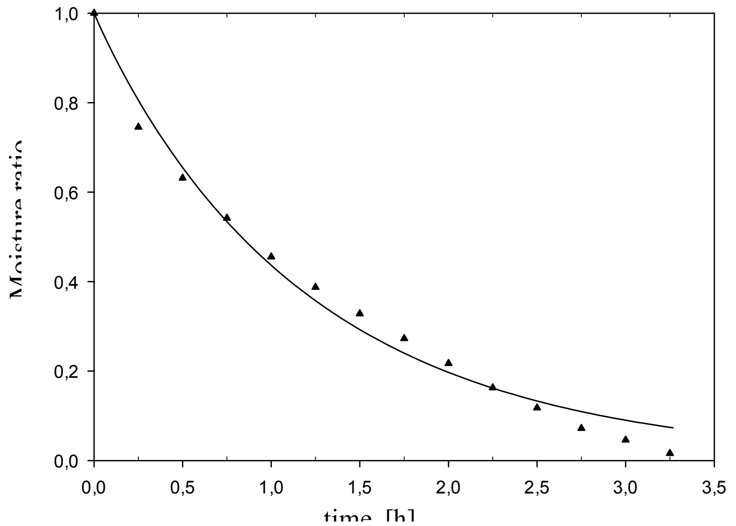


**Fig.9.** Drying behavior of cotton bobbins at $P_{eff}$=1 bar for D=18 cm

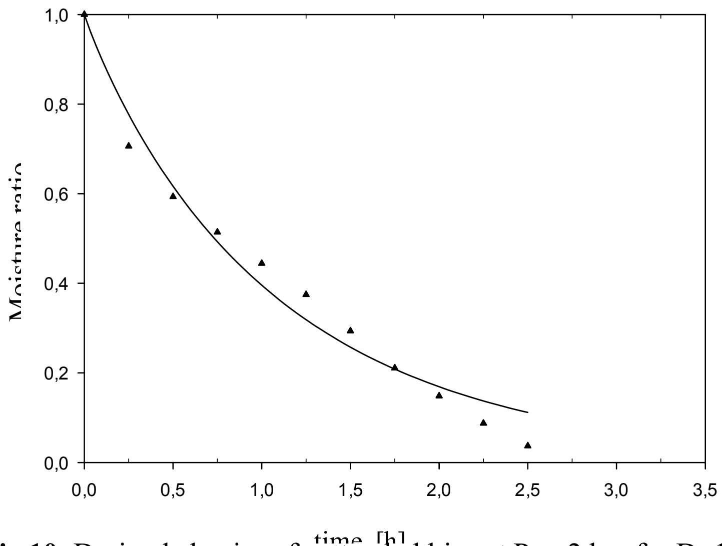


**Fig.10.** Drying behavior of cotton bobbins at $P_{eff}$=2 bar for D=18 cm

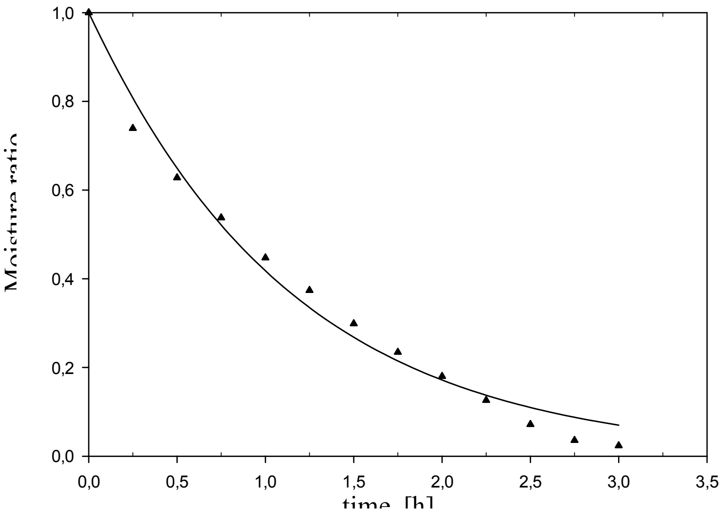


**Fig.11.** Drying behavior of cotton bobbins at $P_{eff}$=3 bar for D=18 cm

**ACKNOWLEDGEMENTS:**

The present work is supported by TÜBİTAK (grants № 108M274).

**REFERENCES**

1. Dincer I, Rosen MA, Exergy: Energy, environment and sustainable development, 2007.
2. Lee HS, Carr WW, Ok H, Industrial drying, CRC Press, 2006.
3. Akyol U, Cihan A, Shaliyev R, Thermophysical parameter estimation of a wool bobbin during convective drying process, Inverse Problems in Science and Engineering, 2010; 18: 227-240.

4. Cihan A, Kahveci K, Akyol U, Akal D, Drying behavior of polyester based yarn bobbins in a hot-air bobbin dryer, Defect and Diffusion Forum, 2011; 312-315: 848-853.
5. Ribeiro J, Ventura JMP, Evaluation of textile bobbins drying processes: experimental and modeling studies, Drying Technology, 1995; 13: 239-265.
6. Lee H.S, Carr WW, Beckham HW, Leisen J, A model of through air drying of tufted textile materials, International Journal of Heat and Mass Transfer, 2002; 45: 357-366.
7. Li Y, Zhu Q, A model of coupled liquid moisture and heat transfer in porous textiles with consideration of gravity, Numerical Heat Transfer, Part A, 2003; 43: 501-523.
8. Akyol U, Kamil K, Cihan A, A study of optimum operating conditions in a convective drying process, HTE'11 Proceedings of the 9th IASME/WSEAS International Conference on Heat Transfer, Thermal Engineering and Environment, 2011; 180-183.
9. Page G, Factors influencing the maximum rates of air-drying shelled corn in thin layers, MS. Dissertation, Lafayette, in Purdue University, 1949.
10. Henderson SM, Pabis S, Grain drying theory I, temperature effect on drying coefficient, Journal of Agricultural Engineering Research, 1961; 6: 169-174.
11. Cihan A, Kahveci K, Hacıhafızoğlu O, Modelling of intermittent drying of thin layer rough rice. Journal of Food Engineering, 2007; 79: 293-298.
12. Wang CY, Singh RP, A thin layer drying equation for rough rice, ASAE 1978; Paper No: 78-3001.
13. Kahveci K, Cihan A, Drying of food materials: transport phenomena, Nova Science, 2008.
14. Sharaf-Eldeen YI, Blaisdell JL, Hamdy MY, A model for ear corn drying, Trans ASAE, 1980; 5: 1261-1265.