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A Software for Calculation of Optimum Conditions for Cotton Bobbin Drying in a Hot-Air Bobbin Dryer

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***Abstract*—**In this study, a software has been developed to predict the optimum conditions for drying of cotton based yarn bobbins in a hot air dryer. For this purpose, firstly, a suitable drying model has been specified using experimental drying behavior for different values of drying parameters. Drying parameters in the experiments were drying temperature, drying pressure, and volumetric flow rate of drying air. After obtaining a suitable drying model, additional curve fittings have been performed to obtain equations for drying time and energy consumption taking into account the effects of drying parameters. Then, a software has been developed using Visual Basic programming language to predict the optimum drying conditions for drying time and energy consumption.

***Keywords*—**Drying, bobbin, cotton, PLC control, Visual Basic.

I. Introduction

YARN bobbins must be dried after dyeing processes in textile industry. Inevitable after most dyeing or/and finishing processes, drying is a time consuming, energy intensive and expensive process and constitutes one of the major cost elements among the textile finishing operations. The purpose of drying is to remove the water inside the bobbin. A part of water in the bobbin is removed mechanically. But this mechanical process is not sufficient to remove water entirely. A convective air dryer is generally used after this process to remove water entirely.

In this study a software has been developed to obtain optimum drying conditions for cotton based yarn bobbins. For this purpose, firstly, a suitable drying model has been specified in defining the drying behaviour of cotton bobbins by fitting the model coefficients to the experimental drying data. After that, further regression analyses have been performed to obtain drying time and energy consumption equations depending on the drying parameters. The developed software predicts the optimum drying conditions using these equations.

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II. Material And Method

The experiments were conducted in a PLC controlled pressurized hot-air bobbin dryer. The schematic view of the experimental setup is shown in Figure 1. Ambient air is directed to an electrical heater by a centrifugal fan and the needed air pressure is obtained by a compressor. After the heater, air enters to a bobbin carrier system where the bobbins are dried. The 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 the carrier, hot air is passed repeatedly 10 minutes from inside to the outside of bobbins and 10 minutes from outside to the inside of the bobbins in radial direction. After carrier, drying air 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 is on a load cell. 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.

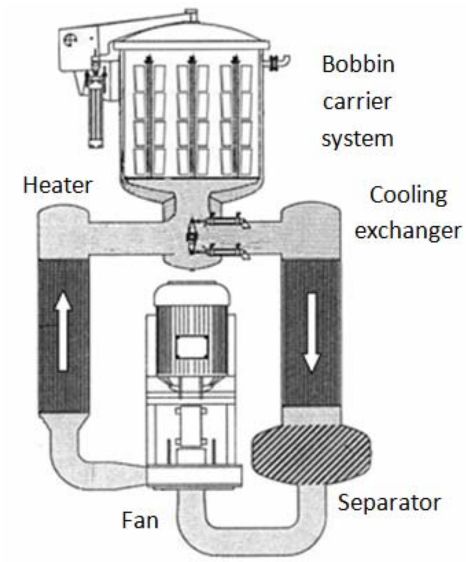

Fig. 1 Schematic view of the experimental bobbin dryer

Drying air is heated in a heating exchanger consisting of 10 electrical resistances of 2.5 kW power. Control of heating power is provided by a solid state relay adjusting the phase difference of sinusoidal wave. Haters are PID (Proportion

Integral Derivate) controlled and temperature adjustment is made according to this algorithm. Feedback control is provided using a Cu-Ni thermocouple. Four double-acting pneumatic pistons with magnetic sensors are used to open, to close and to secure the lid of bobbin carrier and to control the air redirection valve. The pistons are driven by air of 4 bar pressure with the control of valves by outputs of PLC relays.

Fig. 2 Heating exchanger

Fig. 3 Air fan

Fig 4 .Pneumatic pistons

Relative humidity of the drying air at various locations of the system is conveyed to the PLC after measuring it by a sensor of 4-20mA output and 0.1 g/m^3 accuracy. Hot air leaving the bobbin carrier is cooled by a cooling exchanger of 3.89m^2 surface area and 35kW cooling power. After the cooling exchanger, drying air enters to a separator to separate the excess moisture from the drying air.

Fig. 5 Cooling exchanger

Fig. 6 Separator

An analogue loadcell with a 500kg capacity is used to measure the amount of the water removed from the cotton based yarn bobbins.

Fig. 7 Loadcell

Analogue thermocouples of 3-4mm diameter, 10mm length and 4-20A (10 - 350 Ω) output are used to measure the temperature of the drying air at various locations of the experimental setup. The temperature at the outlet of separator is measured with a PT 100 temperature sensor.

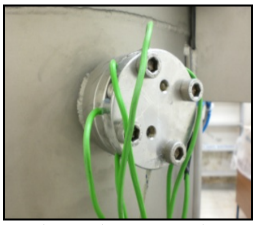
Fig. 8 Thermocouples


Fig. 9 PT100 Temperature sensor

An analogue pressure sensor of 0.5% accuracy and 0-5bar capacity is used to measure the pressure of drying air . The measured value is conveyed to the PLC using the analogue input of the PLC. A casting-bodied, electromagnetic type, analogue flow meter of 4-20mA output is used to measure the volumetric flow rate of the drying air.


Fig. 10 Pressure sensor


Fig. 11 Flow meter

The control of the drying system is provided by a Siemens S7-200 PLC. By the Ladder diagram of controlling software, drying conditions are observed and controlled on a touch-operated screen. The control panel is shown in Figure 12.


Fig. 12 Control panel

III. Analysis

Four different drying models given in Table 1 are taken into account for determination of the most appropriate model for simulation of drying of cotton based yarn bobbins.

TABLE I
DRYING MODELS

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

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

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

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

IV. Results And Conclusion

The dimensions of the bobbins used in the experiments are shown in Table 2. The experimental results were obtained for drying temperature of 70°C, 80°C, and 90°C, for effective drying pressure of 1bar and 2bar, for volumetric flow rate of $42.5m^3/h$, $55.0m^3/h$, and $67.5m^3/h$ per bobbin. Curve fitting computations were carried out on the four drying models given in Table 1 relating the drying time and moisture ratio. The results show that the most appropriate model in describing the drying curves of cotton based yarn bobbins is the Page model. Additional regression analyses have been carried out to obtain equations for drying time and energy consumption depending on the drying parameters. The results are shown in Table III.

TABLE II
DIMENSIONS OF THE BOBBINS

H (cm)	d (cm)	D (cm)
15.5	5.4	10
		14
		18

After the equations for drying time and energy consumption were obtained, a software was developed using the Visual Basic programming language. With the aid of this software, optimum drying conditions for drying time and energy consumption can be obtained. The main window of the developed software is shown in Figure 13.

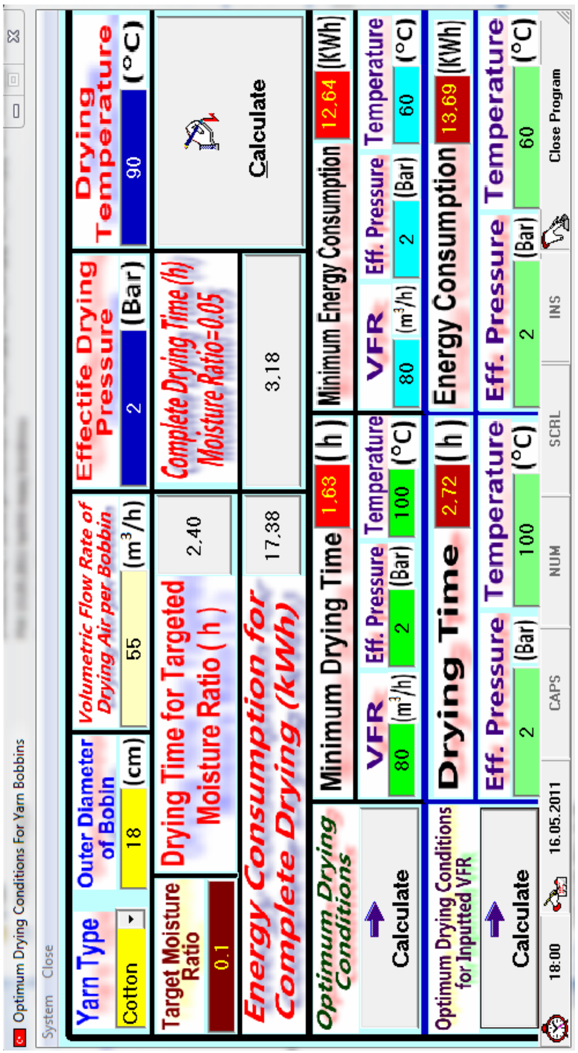

Fig. 13 The main window of the developed program

TABLE III
DRYING TIME AND ENERGY CONSUMPTION EQUATIONS.

$mr = \exp(-kt^n)$, $t = \left[-\ln(mr)/k\right]^{1/n}$, $k = a_1D + a_2Q + a_3P + a_4T + a_5DQ + a_6DP + a_7DT + a_8QP + a_9QT + a_{10}PT + a_{11}$

a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}	a_{11}	RMSE
-0.090901	-0.006198	-0.595933	-0.002284	0.000133	0.001528	0.000043	0.009009	0.000117	0.003583	1.911970	0.057

$n = b_1D + b_2Q + b_3P + b_4T + b_5DQ + b_6DP + b_7DT + b_8QP + b_9QT + b_{10}PT + b_{11}$

b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	b_9	b_{10}	b_{11}	RMSE
0.057598	-0.015140	0.157267	-0.011888	-0.000463	-0.006528	0.000059	-0.000729	0.000284	-0.000711	0.891893	0.050

$E = f_1D + f_2Q + f_3P + f_4T + f_5DQ + f_6DP + f_7DT + f_8QP + f_9QT + f_{10}PT + f_{11}$

f_1	f_2	f_3	f_4	f_5	f_6	f_7	f_8	f_9	f_{10}	f_{11}	RMSE
-0.352736	0.311404	11.660111	0.421169	-0.010612	0.163406	0.012292	0.016058	-0.003241	-0.170761	-24.90312	1.038

The software has three sections. In the uppermost first section, there are boxes to input the drying parameters: outer diameter of bobbins and volumetric flow rate of the drying air per bobbin, effective drying pressure and drying temperature. If the calculate button is pressed, drying time and energy consumption are calculated by the software for the inputted values of the parameters. In the middle second section, optimum conditions for drying time and energy consumption are shown on the screen for inputted outer diameter of bobbin after the calculate button is pressed. In the under most third section, optimum conditions for drying time and energy consumption are shown on the screen for inputted outer diameter of bobbin and volumetric flow rate of drying air per bobbin after the calculate button is pressed. In the software developed, the coefficients in the equations for drying time and energy consumption are assigned to the elements of a matrix as shown in Figure 14. The calculation procedure for the optimum drying conditions is shown in Figure 15.

```
Private Sub cmbTip_Change()
If cmbTip.Text = "Cotton" Then
    a(1) = -0.090901: b(1) = 0.057598: c(1) = -0.352736
    a(2) = -0.006198: b(2) = -0.01514: c(2) = 0.311404
    a(3) = -0.595933: b(3) = 0.157267: c(3) = 11.660111
    a(4) = -0.002284: b(4) = -0.011888: c(4) = 0.421169
    a(5) = 0.000133: b(5) = -0.000463: c(5) = -0.010612
    a(6) = 0.001528: b(6) = -0.006528: c(6) = 0.163406
    a(7) = 0.000043: b(7) = 0.000059: c(7) = 0.012292
    a(8) = 0.009009: b(8) = -0.000729: c(8) = 0.016058
    a(9) = 0.000117: b(9) = 0.000284: c(9) = -0.003241
    a(10) = 0.003583: b(10) = -0.000711: c(10) = -0.170761
    a(11) = 1.91197: b(11) = 0.891893: c(11) = -24.903115
```

Fig. 14 Coefficients of the equations

```
Private Sub Command1_Click()
On Error GoTo hata
Dim k, n, j, ee, tt As Double
Dim kucukZaman, kucukEnerji, kucukBasinc, kucukDebi, ku
Dim r, i, z As Integer
Dim t(700), e(700), Sicaklik(700), Basinc(700), Debi(70
r = 0
'-----------------------------
For i = 30 To 80 Step 5
    For j = 0.5 To 2 Step 0.25
        For z = 60 To 100 Step 5
            k = a(1) * Val(txtCap.Text) + a(2) * i + a(
            a(6) * Val(txtCap.Text) * j + a(7) * Val(tx
            n = b(1) * Val(txtCap.Text) + b(2) * i + b(
            b(6) * Val(txtCap.Text) * j + b(7) * Val(tx
            ee = c(1) * Val(txtCap.Text) + c(2) * i + c
            c(6) * Val(txtCap.Text) * j + c(7) * Val(tx
            ee = Int(ee * 100) / 100
            tt = Abs((-Log(0.05) / k)) ^ (1 / n)
            tt = Int(tt * 100) / 100
            t(r) = tt: e(r) = ee
            Sicaklik(r) = z: Basinc(r) = j: Debi(r) = i
            r = r + 1
        Next z
    Next j
Next i
r = r - 1
kucukZaman = t(0): kucukBasinc = Basinc(0): kucukDebi =
For i = 0 To r - 1
        If t(i + 1) < t(i) Then
            kucukZaman = t(i + 1)
            kucukBasinc = Basinc(i + 1)
            kucukDebi = Debi(i + 1)
            kucukSicaklik = Sicaklik(i + 1)
        End If
Next i
```

Fig. 15 Calculation procedure of optimum drying conditions

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