A software for calculation of optimum conditions for cotton, viscose, polyester and wool based yarn bobbins in a hot-air bobbin dryer

H. Kuşçu, K. Kahveci, U. Akyol and A. Cihan

***Abstract*—**In this study, a software has been developed to predict the optimum drying conditions of viscose, wool, polyester and cotton based yarn bobbins for drying in a pressurized hot air dryer. For this purpose, firstly, a suitable drying model has been found in defining the drying behavior of bobbins using the experimental drying behavior. After that, additional regression analyses have been made to take into account the effect of the drying parameters on drying. Then, a software has been developed using Visual Basic programming language. With the aid of this software, optimum drying conditions for drying time and energy consumption can be obtained for the cotton, viscose, polyester and wool based yarn bobbins.

***Keywords*—**Drying, Optimum conditions, Moisture ratio, Visual basic, Yarn bobbins.

I. Introduction

THE main objective of any drying process is to produce a dried product of desired quality at minimum cost and maximum throughput and to optimize these factors consistently [1, 2]. 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. Part of the water in the bobbins is removed mechanically. But this mechanical process is not sufficient to remove water entirely. Therefore, a pressurized convective air dryer is generally used after this process.

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. Therefore it is very important to determine optimum drying conditions and accordingly to develop automatic control systems, drying algorithms and software in such systems. For example in a study performed by Yankov and Deliiski (2007), a programmable control system for the convective drying of lumber in chambers is developed, based on specially designed drying algorithm [3]. In another study, technical considerations for design and construction of the experimental model for an automatic microwave drying system for construction materials have been presented [4].

In this study, a software has been developed to obtain optimum drying conditions for viscose, wool, polyester and cotton based yarn bobbins. For this purpose, firstly, a suitable drying model has been found in defining the drying behavior of bobbins using the experimental drying behavior. After that, further regression analyses have been performed to obtain drying time and energy consumption equations depending on the drying parameters. The developed software specifies the optimum drying conditions using these equations.

II. Material and Method

A PLC controlled pressurized hot-air bobbin dryer was used to obtain the drying behavior of viscose, wool, polyester and cotton based yarn bobbins. The schematic view of the experimental setup is shown in Fig. 1.

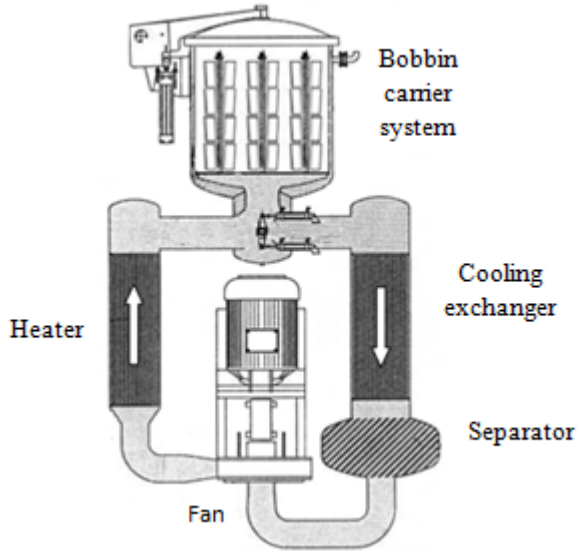

Fig. 1 schematic view of the experimental bobbin dryer

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H. Kuşçu, K. Kahveci and A. Cihan is with the Mechanical Engineering Department, Trakya University, Edirne, Turkey (phone: 0090-532-4953660; fax: 0090-284-2261217; e-mail: hilmi@trakya.edu.tr).

U. Akyol is with the Mechanical Engineering Department, Çorlu Faculty of Engineering, Namik Kemal University, Çorlu, Tekirdag, Turkey (phone: 0090-282-6529475; fax: 0090-282-6529372; e-mail: uakyol@nku.edu.tr).

Ambient air is directed to an electrical heater by a centrifugal fan. Pressurization is realized 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. 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 the carrier, drying air enters to a cooling exchanger and relative humidity of drying air is reduced. Next, 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. The conditions of air at different locations 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.

Drying air is heated in a heating exchanger (Fig. 2) consisting of 10 electrical resistances of 2.5 kW power. The control of heating power is realized by a solid state relay adjusting the phase difference of sinusoidal wave. Haters are PID (Proportion Integral Derivate) controlled and temperature adjustment is carried out according to this algorithm. Feedback control is provided using a Cu-Ni thermocouple. Four double-acting pneumatic pistons (Fig. 3) with magnetic sensors are used to open, to close, and to secure the lid of bobbin carrier and to control the air redirecting valve. The pistons are driven by pressurized air of 4 bar with the control of valves by outputs of PLC relays.

Relative humidity of the drying air at various locations 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 (Fig. 4). After the cooling exchanger, drying air enters to a separator (Fig. 5) and excess moisture is separated from the drying air.

Fig. 3a pneumatic pistons

Fig. 3b pneumatic pistons

Fig. 2 heating exchanger

Fig. 4 cooling exchanger

Fig. 5 separator

An analogue loadcell (Fig. 6) with a 600kg capacity has been used to measure the weight of the bobbins during the drying period. The loadcells are under the bobbin carrier and have 3 load cells.

Fig. 6 loadcell

Analogue thermocouples of 3-4mm diameter, 10mm length and 4-20A (10 - 350 Ω) output (Fig. 7) are used to measure the temperature of the drying air at various location of the experimental setup. The temperature at output of separator has been measured with a PT 100 temperature sensor (Fig. 8).

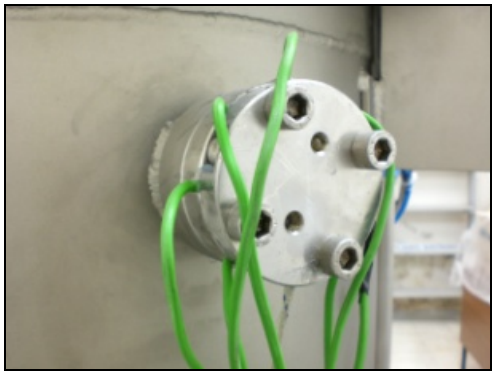


Fig. 7 thermocouples

Fig. 8 PT100 sensors

An analogue pressure sensor of 0.5% accuracy and 0-5bar capacity (Fig. 9e is conveyed to the PLC using the analogue input of the PLC.

Fig. 9 pressure sensor

A casting-bodied, electromagnetic type, analogue volumetric flow meter of 4-20mA output (Fig. 10) is used to measure the volumetric flow rate of the drying air.

Fig. 10 flow meter

Control of the drying system is provided by a Siemens S7-200 PLC (Fig. 11). By the Ladder diagram of controlling software, drying conditions are observed and controlled on a touch-operated screen.

Fig. 11 control panel

The experimental study is carried out for various values of four different drying parameters: temperature, pressure, volumetric flow rate, and bobbin outer diameter. The moisture ratio of the bobbins and energy consumption during drying are monitored during drying.

III. Problem Formulation

Four different empirical or semi empirical drying models given in Table 1 are taken into account to determine the most appropriate model for drying simulation of viscose, wool, polyester and cotton based yarn bobbins.

Table 1 drying models

Name	Model equation	Ref.
Page	$mr = exp(-kt^n)$	[5]
Henderson and Pabis	$mr = a\,exp(-kt)$	[6]
Geometric	$mr = at^{-n}$	[7]
Wang and Singh	$mr = 1 + at + bt^2$	[8]

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

IV. Problem Solution

Schematic view and geometrical dimensions for the bobbins used in the experiments are shown in Fig. 12 and Table 2 respectively. 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 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 viscose, wool, polyester and cotton based yarn bobbins is the Page model. After obtaining the coefficients of the Page model, additional regression analyses have been carried out to obtain equations for drying time and energy consumption depending on the drying parameters.

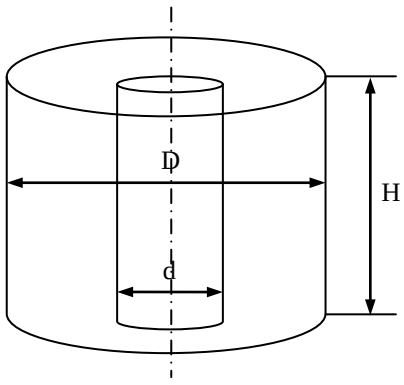


Fig. 12 bobbin geometry.

Table 2 dimensions of the bobbins

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

Moisture ratio mr is calculated by the following equation:

$$mr = exp\left(-kt^n\right) \tag{2}$$

Drying time t can be calculated by the following equation:

$$t = \left[-ln\left(mr\right)/k\right]^{1/n} \tag{3}$$

Here, values of k and n are calculated by the equations 4 and 5 respectively:

$$k = a_1 D + a_2 Q + a_3 P + a_4 T + a_5 DQ + a_6 DP + a_7 DT + a_8 QP + a_9 QT + a_{10} PT + a_{11} \tag{4}$$

$$n = b_1 D + b_2 Q + b_3 P + b_4 T + b_5 DQ + b_6 DP + b_7 DT + b_8 QP + b_9 QT + b_{10} PT + b_{11} \tag{5}$$

The coefficients in equations 4 and 5 depending on the type of yarn as a result of the data obtained from experiments in such a way that the most appropriate value given in the table 3 and 4 respectively.

Table 3 values of the coefficients a depending on yarn types

Const.	Yarn Type			
	Cotton	Wool	Viscose	Polyester
a_1	-0.090901	-0.079528	-0.082970	-0.084809
a_2	-0.006198	-0.017575	-0.003521	-0.001001
a_3	-0.595933	0.296180	0.015623	-1.085839
a_4	-0.002284	-0.003507	-0.005693	0.000968
a_5	0.000133	0.000018	0.000022	-0.000843
a_6	0.001528	0.000749	0.000889	-0.005306
a_7	0.000043	-0.000001	0.000008	0.000059
a_8	0.009009	-0.001191	0.000231	0.010338
a_9	0.000117	0.000355	0.000165	0.000522
a_{10}	0.003583	-0.002156	0.000772	0.010306
a_{11}	1.911970	1.530501	1.686960	1.714797
RMSE	0.057	0.042	0.035	0.130

Table 4 values of the coefficients b depending on yarn types

Const.	Yarn Type			
	Cotton	Wool	Viscose	Polyester
b1	0.057598	0.049192	0.046697	0.042584
b2	-0.015140	-0.000962	-0.005618	0.016956
b3	0.157267	-0.042354	0.035802	0.107121
b4	-0.011888	-0.000924	-0.002806	0.009579
b5	-0.000463	-0.000302	-0.000120	-0.000534
b6	-0.006528	-0.000375	-0.003958	-0.007875
b7	0.000059	0.000059	0.000104	0.000132
b8	-0.000729	0.000280	0.001649	-0.000178
b9	0.000284	0.000090	0.000098	-0.000107
b10	-0.000711	0.000206	-0.000694	-0.000728
b11	0.891893	0.120865	0.298765	-0.598400
RMSE	0.050	0.043	0.049	0.036

Equation 6 was used to calculate the energy consumption:

$$E = c_1 D + c_2 Q + c_3 P + c_4 T + c_5 DQ + c_6 DP + c_7 DT + c_8 QP + c_9 QT + c_{10} PT + c_{11} \quad (6)$$

The coefficients used in equation 6, obtained from experimental data are determined to provide the most appropriate value given in Table 5.

Table 5 values of the coefficients c depending on yarn types

Const.	Yarn Type			
	Cotton	Wool	Viscose	Polyester
c_1	-0.352736	1.850568	-0.366154	0.205882
c_2	0.311404	0.249503	0.529711	-0.057634
c_3	11.660111	9.935408	9.516899	5.267320
c_4	0.421169	0.433818	0.659287	0.107152
c_5	-0.010612	-0.013869	-0.012119	-0.000276
c_6	0.163406	0.145861	0.287709	0.037935
c_7	0.012292	-0.009804	0.011125	-0.001608
c_8	0.016058	0.056783	0.019661	0.003871
c_9	-0.003241	-0.001371	-0.006218	0.000690
c_{10}	-0.170761	-0.144440	-0.156664	-0.065356
c_{11}	-24.903115	-38.896845	-35.594517	-5.444298
RMSE	1.038	0.767	1.403	0.229

V. RESULTS AND DISCUSSION

Using the equations for drying time and energy consumption, 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 Fig. 13.

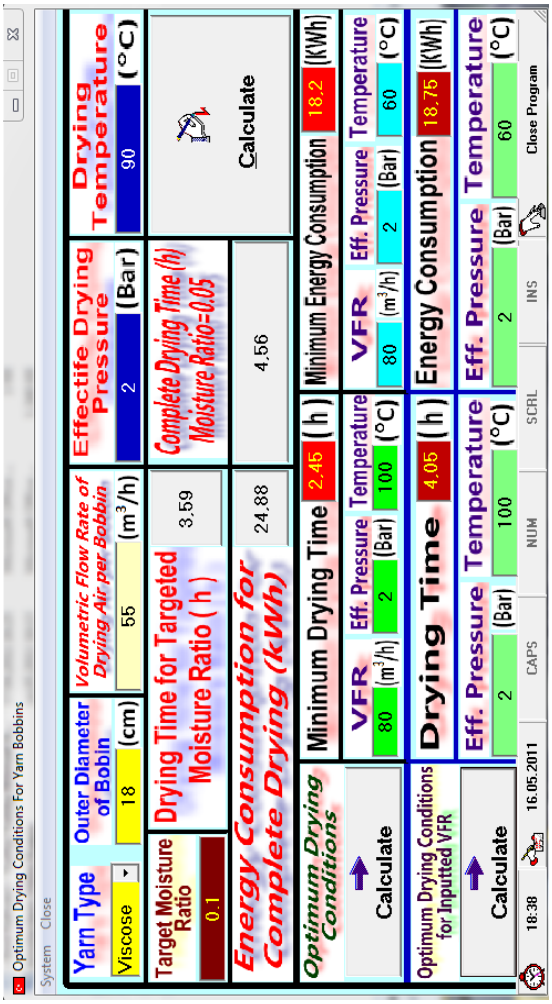


Fig. 13 main window of the developed software

As shown in Fig. 12, software has three sections. In the uppermost first section, there are boxes to input the values of parameters: outer diameter of bobbins, volumetric flow rate of the drying air per bobbin, effective drying pressure and drying temperature. See Fig. 14.

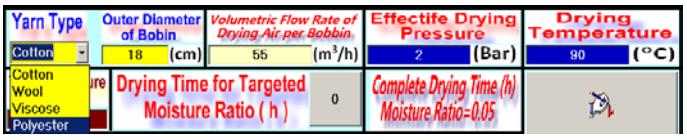


Fig. 14 first section of the software

If the calculate button is pressed, drying time and energy consumption are calculated by the software for the inputted values of the parameters, as you have seen in figure 15.

Fig. 15 drying time and energy consumption

In the middle second section, optimum conditions for drying time and energy consumption is shown on the screen for the inputted outer diameter of bobbin after the calculate button is pressed, as you have seen in figure 16.

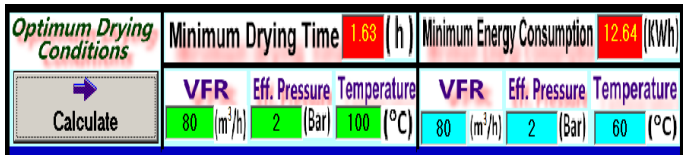


Fig. 16 optimum conditions for drying time and energy consumption

In the undermost third section, optimum conditions for drying time and energy consumption is shown on the screen for the inputted outer diameter of bobbin and volumetric flow rate of drying air per bobbin after the calculate button is pressed, as you have seen in figure 17.

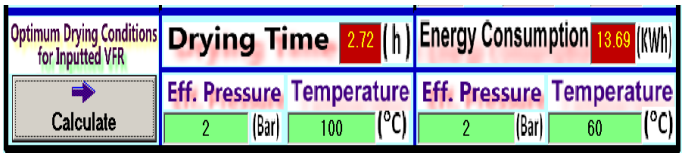


Fig. 17 optimum drying conditions for inputted VFR

In the code developed, the coefficients including in the equations for drying time and energy consumption are assigned to the elements of a matrix as shown in Figs. 18a-d. The calculation procedure of optimum drying conditions is shown in Fig. 19.

```
Private Sub cmbTip_Change()
If cmbTip.Text = "Viscose" Then
    a(1) = -0.08297: b(1) = 0.046697: c(1) = -0.366154
    a(2) = -0.003521: b(2) = -0.005618: c(2) = 0.529711
    a(3) = 0.015623: b(3) = 0.035802: c(3) = 9.516899
    a(4) = -0.005693: b(4) = -0.002806: c(4) = 0.659287
    a(5) = 0.000022: b(5) = -0.00012: c(5) = -0.012119
    a(6) = 0.000889: b(6) = -0.003958: c(6) = 0.287709
    a(7) = 0.000008: b(7) = 0.000104: c(7) = 0.011125
    a(8) = 0.000231: b(8) = 0.001649: c(8) = 0.019661
    a(9) = 0.000165: b(9) = 0.000098: c(9) = -0.006218
    a(10) = 0.000772: b(10) = -0.000694: c(10) = -0.156664
    a(11) = 1.68696: b(11) = 0.298765: c(11) = -35.594517
End If
```

Fig. 18a coefficients of the equations for viscose yarn

```
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. 18b coefficients of the equations for cotton yarn

```
If cmbTip.Text = "Wool" Then
    a(1) = -0.079528: b(1) = 0.049192: c(1) = 1.850568
    a(2) = -0.017575: b(2) = -0.000962: c(2) = 0.249503
    a(3) = 0.29618: b(3) = -0.042354: c(3) = 9.935408
    a(4) = -0.003507: b(4) = -0.000924: c(4) = 0.433818
    a(5) = 0.000018: b(5) = -0.000302: c(5) = -0.013869
    a(6) = 0.000749: b(6) = -0.000375: c(6) = 0.145861
    a(7) = -0.000001: b(7) = 0.000059: c(7) = -0.009804
    a(8) = -0.001191: b(8) = 0.00028: c(8) = 0.056783
    a(9) = 0.000355: b(9) = 0.00009: c(9) = -0.001371
    a(10) = -0.002156: b(10) = 0.000206: c(10) = -0.14444
    a(11) = 1.530501: b(11) = 0.120865: c(11) = -38.896845
End If
```

Fig. 18c Coefficients of the equations for wool yarn

```
If cmbTip.Text = "Polyester" Then
    a(1) = -0.084809: b(1) = 0.042584: c(1) = 0.205882
    a(2) = -0.001001: b(2) = 0.016956: c(2) = -0.057634
    a(3) = -1.085839: b(3) = 0.107121: c(3) = 5.26732
    a(4) = 0.000968: b(4) = 0.009579: c(4) = 0.107152
    a(5) = -0.000843: b(5) = -0.000534: c(5) = -0.000276
    a(6) = -0.005306: b(6) = -0.007875: c(6) = 0.037935
    a(7) = 0.000059: b(7) = 0.000132: c(7) = -0.001608
    a(8) = 0.010338: b(8) = -0.000178: c(8) = 0.003871
    a(9) = 0.000522: b(9) = -0.000107: c(9) = 0.00069
    a(10) = 0.010306: b(10) = -0.000728: c(10) = -0.065356
    a(11) = 1.714797: b(11) = -0.5984: c(11) = -5.444298
End If
```

Fig. 18d Coefficients of the equations for polyester yarn

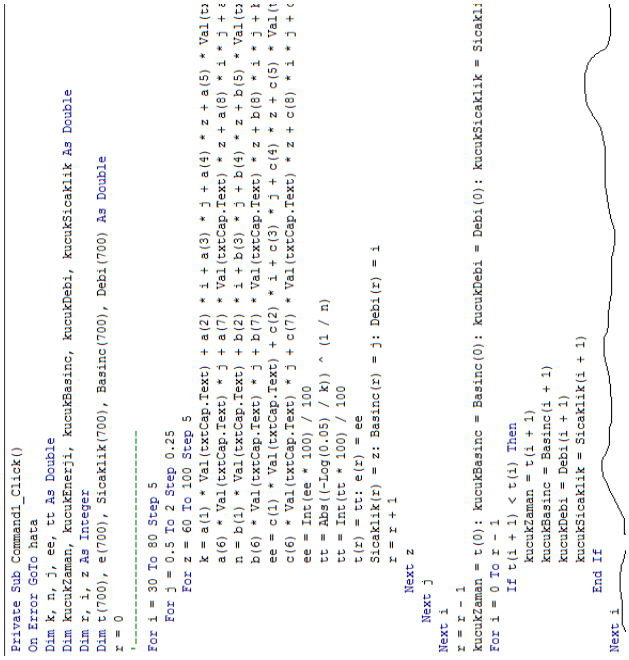
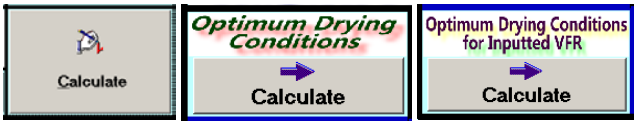


Fig. 19 Calculation procedure for optimum drying conditions

There are three calculation buttons in the developed code (Fig. 20). The calculation procedures for these buttons are given in Fig. 21.



a b c

Fig. 20 calculation buttons

```
Private Sub CmdHesap_Click()
Dim n, k, t, e As Double
k = a(1) * Val(txtCap.Text) + a(2) * Val(txtDe
a(4) * Val(txtSicaklik.Text) + a(5) * Val(txt(
a(6) * Val(txtCap.Text) * Val(TxtBar.Text) + a
a(8) * Val(txtDebi.Text) * Val(TxtBar.Text) +
a(10) * Val(TxtBar.Text) * Val(txtSicaklik.Tex
'---------------------------------
n = b(1) * Val(txtCap.Text) + b(2) * Val(txtDe
b(4) * Val(txtSicaklik.Text) + b(5) * Val(txt(
b(6) * Val(txtCap.Text) * Val(TxtBar.Text) + b
b(8) * Val(txtDebi.Text) * Val(TxtBar.Text) +
b(10) * Val(TxtBar.Text) * Val(txtSicaklik.Tex
'--------------------
t = (-Log(Val(TxtNem.Text)) / k) ^ (1 / n)
t = Format(t, "###0.00")

CmdDTTMR.Caption = t
'----------------------------
t = (-Log(0.05) / k) ^ (1 / n)
t = Format(t, "###0.00")
CmdCDTM.Caption = t
'---------------------------
e = c(1) * Val(txtCap.Text) + c(2) * Val(txtDe
c(5) * Val(txtCap.Text) * Val(txtDebi.Text) +
c(8) * Val(txtDebi.Text) * Val(TxtBar.Text) +
c(10) * Val(TxtBar.Text) * Val(txtSicaklik.Tex
'---------------------------------

CmdAECCD.Caption = Format(e, "###0.00")
End Sub
```

Fig. 21a calculation procedure for a button

```
Private Sub Command1_ODC()
Dim k, n, j, ee, tt As Double
Dim kucukZaman, kucukEnerji, kucukBasinc, _
kucukDebi, kucukSicaklik As Double
Dim r, i, z As Integer
Dim t(800), e(800), Sicaklik(800), Basinc(800), _
Debi(800) As Double
r = 0
For i = 20 To 90 Step 5
    For j = 0 To 3 Step 0.5
        For z = 50 To 120 Step 5
            k = a(1) * Val(txtCap.Text) + a(2) * _
            i + a(3) * j + a(4) * z + a(5) * _
            Val(txtCap.Text) * i + a(6) * _
            Val(txtCap.Text) * j + a(7) * Val(txtCap.Text) _
            * z + a(8) * i * j + a(9) * i * z + _
            a(10) * j * z + a(11)
            n = b(1) * Val(txtCap.Text) + b(2) _
            * i + b(3) * j + b(4) * z + b(5) * _
            Val(txtCap.Text) * i + b(6) * Val(txtCap.Text) _
            * j + b(7) * Val(txtCap.Text) * z + b(8) * i * _
            j + b(9) * i * z + b(10) * j * z + b(11)
            ee = c(1) * Val(txtCap.Text) + c(2) * i + c(3) _
            * j + c(4) * z + c(5) * Val(txtCap.Text) * i + _
            c(6) * Val(txtCap.Text) * j + c(7) * _
            Val(txtCap.Text) * z + c(8) * i * j + c(9) * i _
            * z + c(10) * j * z + c(11)
            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
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
      txtDFR.Text = kucukDebi
      txtDP.Text = kucukBasinc
      txtDT.Text = kucukSicaklik
      txtMDT.Text = kucukZaman

   kucukEnerji = e(0): kucukBasinc = Basinc(0):
   kucukDebi = Debi(0): kucukSicaklik = Sicaklik(0)
   For i = 0 To r - 1
           If e(i + 1) < e(i) Then
                kucukEnerji = e(i + 1)
                kucukBasinc = Basinc(i + 1)
                kucukDebi = Debi(i + 1)
                kucukSicaklik = Sicaklik(i + 1)
           End If
   Next i
      txtEFR.Text = kucukDebi
      txtEP.Text = kucukBasinc
      txtET.Text = kucukSicaklik
      txtMEC.Text = kucukEnerji

   Exit Sub
   hata:
   MsgBox "Errror..."
   End Sub
```

Fig. 21b calculation procedure for b button

```
Private Sub Command2_FVR()
Dim k, n, j, ee, tt As Double
Dim kucukZaman, kucukEnerji, kucukBasinc, _
kucukSicaklik As Double
Dim r, z, i As Integer
Dim t(700), e(700), Sicaklik(700), _
Basinc(700)  As Double
r = 0
    For j = 0.5 To 2 Step 0.25
        For z = 60 To 100 Step 5
            k = a(1) * Val(txtCap.Text) + a(2) * Val(txtDebi.Text) _
            + a(3) * j + a(4) * z + a(5) * Val(txtCap.Text) * _
            Val(txtDebi.Text) + _
            a(6) * Val(txtCap.Text) * j + a(7) * Val(txtCap.Text) _
            * z + a(8) * Val(txtDebi.Text) * j + a(9) * _
            Val(txtDebi.Text) * z + a(10) * j * z + a(11)
            n = b(1) * Val(txtCap.Text) + b(2) * Val(txtDebi.Text) _
            + b(3) * j + b(4) * z + b(5) * Val(txtCap.Text) * _
            Val(txtDebi.Text) + b(6) * Val(txtCap.Text) * j + _
            b(7) * Val(txtCap.Text) * z + b(8) * Val(txtDebi.Text) _
            * j + b(9) * Val(txtDebi.Text) * z + b(10) * j * z + b(11)
            ee = c(1) * Val(txtCap.Text) + c(2) * Val(txtDebi.Text) _
            + c(3) * j + c(4) * z + c(5) * Val(txtCap.Text) * _
            Val(txtDebi.Text) + c(6) * Val(txtCap.Text) * j + c(7) _
            * Val(txtCap.Text) * z + c(8) * Val(txtDebi.Text) * j + _
            c(9) * Val(txtDebi.Text) * z + c(10) * j * z + c(11)
            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
           r = r + 1
        Next z:  Next j
r = r - 1
For i = 0 To r - 1
        If t(i + 1) < t(i) Then
            kucukZaman = t(i + 1)
            kucukBasinc = Basinc(i + 1)
            kucukSicaklik = Sicaklik(i + 1)
                    kucukSicaklik = Sicaklik(i + 1)
                End If
         Next i
            txtDP2.Text = kucukBasinc
            txtDT2.Text = kucukSicaklik
            txtMDT2.Text = kucukZaman
         kucukEnerji = e(0): kucukBasinc = Basinc(0)
         kucukSicaklik = Sicaklik(0) '

         For i = 0 To r - 1
                If e(i + 1) < e(i) Then
                    kucukEnerji = e(i + 1)
                    kucukBasinc = Basinc(i + 1)
                    kucukSicaklik = Sicaklik(i + 1)
                End If
         Next i
            txtEP2.Text = kucukBasinc
            txtET2.Text = kucukSicaklik
            txtMEC2.Text = kucukEnerji
         End Sub
```

Fig. 21a calculation procedure for c button

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