



Optimisation of dyeing temperature with PID Controller and Effect on dyed Cotton fabric properties

Prof. J. Hayavadana, Ahmed Hashim Raza, Mohammed Mahtab Ahmed, Mohd Muzammil, Pravallika Gadiraju
University College of Technology, Osmania University, Hyderabad, India.

Abstract:

Dyeing is one of the important Textile wet Processing stage and due to advancement in Science and Technology , approach to acquire uniform dye shade with minimum heat energy. This work comprises using a closed loop PID controller to maintain a constant temperature in the dyebath to attain uniform dye shade. The PID controller with its three variable parameters (proportional-integral-derivative) control the temperature of dyeing by minimizing past, present and future errors in the process circuit ensuring a controlled dyeing. The fabric was characterised for physical properties and results are interpreted with and with out use of PID for dyeing .

Keywords: Dyeing , fabric , PID controller, time

1.0 INTRODUCTION:

Dyeing is one of the important textile wet processing stages in the production of finished fabric. Wide range of machines with different principles are being used from long time. During the past three decades all the stages of wet processing has witnessed a great deal of development due to advancements in science and technology innovations. Among the various parameters of dyeing , treatment temperature is one of the important factor controlling the quality of dyed goods. Today¹ the machines are developed with computer control hardware and in the present study the potential of PID controller is explored to control the temperature .

A PID controller works on the principle of control loop feedback that calculates the error (Figure 1 & 2) value as the difference between a measured process variable and a desired set value. This error is controlled and minimized by adjusting the process through the introduction of a manipulated variable in the system. The mechanism of a PID controller works by adding up errors from the past, present and future and adjusting the output value using the control element. PID expands as proportional (present), integral (past) and derivative (future); and these three actions are responsible for controlling the output of the process. A PID controller is considered the most useful and efficient controller thanks to its three-way control although it does not guarantee complete stability of the system as it depends on the responsiveness of the controller to the error, the degree of overshooting past the setpoint value and the degree of oscillation of the system. The PID can act as P, PI, PD or I controller depending on the action required which is achieved by setting the other parameters to zero [2].

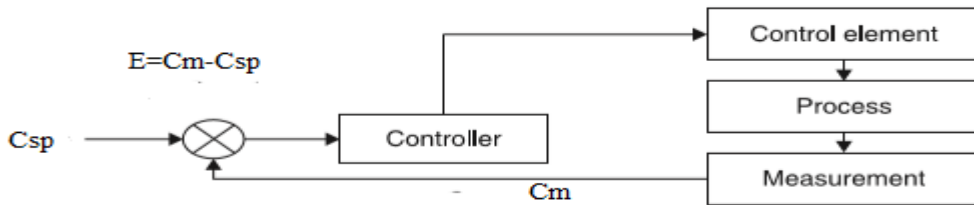


Fig. 1. Representation of Control loop

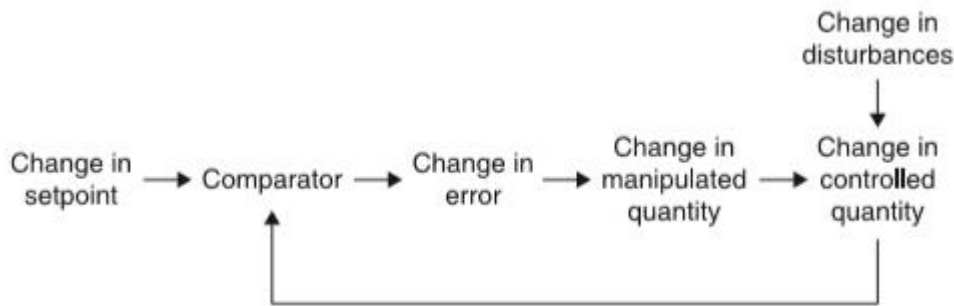


Fig. 2. Feedback control system

PID controller [3,4] is the most widely used controller in the industry. A PID controller has three parameters- proportional constant ‘KP’, integral constant ‘KI’ and the derivative constant ‘KD’. These three parameters are meant to take care of the present, future and the past errors. A PID controlled process having system transfer function ‘Gs’ and unity feedback is shown in Fig. 3.



Fig.3. PID Controller

‘Gc’ is the transfer function of the PID controller and is given by equation (1) and (2)

$$G_c = K_p + \frac{K_I}{s} + K_D s \quad \dots\dots\dots (1)$$

$$G_c = K_p \left(1 + \frac{1}{T_i s} + T_d s \right) \quad \dots\dots\dots (2)$$

The three modes of the controller; proportional, integral and derivative, are arranged into three main control structures. They are interactive, non-interactive and parallel algorithms. Depending on the mode of control, the algorithm can be chosen as required which is inbuilt by the maker of the controller [3]. The following equations can be expressed for three modes

Interactive Algorithm: $u(t) = Kc[e(t) + \frac{1}{T_i} \int e(\tau) d\tau + T_d \frac{d}{dt} e(t)] \dots\dots\dots (3)$

Non-Interactive Algorithm: $u(t) = Kc[e(t) + \frac{1}{T_i} \int e(\tau) d\tau + T_d \frac{d}{dt} e(t)] \dots\dots\dots (4)$

Parallel Algorithm: $u(t) = Kp e(t) + Ki \int e(\tau) d\tau + Kd \frac{d}{dt} e(t) \dots\dots\dots (5)$

Where, $K_p = K_c$: Proportional gain, $K_i = \frac{K_c}{T_i}$: Integral gain and $K_d = K_c T_d$: derivative gain ,

$$e(t)=r(t)-y(t) \dots\dots\dots (6)$$

There are different tuning methods Ziegler-Nichols and Cohen-Coon . Few of the research papers have explored the use of PID (4- 9).Different types of PID can be found like : on-off, proportional and PID. Depending upon the system to be controlled, the operator will be able to use one type or another to control the process.

1.1 Concluding remarks about literature review

The methodology includes in tuning the PID by Ziegler-Nichols method and carrying the dyeing of cotton fabric with different temperate . The study is aimed to find out the effect of treatment temperature on the fabric properties and the information about this in the literature is sparse and thus the thrust of the present study is to explore the same.

2.0 Methodology

As a first step tuning of the PID by Ziegler-Nichols method was carried out and transfer function model of the temperature control system was established .In the second step the time taken to reach the set points was analysed The transfer function is also given in the next paragraphs. The fabric was dyed as per the standard procedure given by Trotman[5] .

2.1 Details of Experimental Fabric.

The geometrical properties of the experimental fabrics chosen is as follows

Table 1 Geometrical properties of Experimental fabrics

Parameters	Sample 1	Sample 2	Sample 3
Count	2/80s	2/80s	2/80s
Ends per cm	100	100	100
Picks per cm	82	92	102
length	10cm	10cm	10cm
width	10cm	10cm	10cm
weight	1.31g	1.41g	1.51g

The fabrics selected were such that the count and ends/cm was same for both fabrics to have commonality.

2.2 Details of the treatment conditions

The experimental grey fabric was desized as per the standard procedure explained by Trotman [5]. The desized fabric was dyed using direct dyes C.I. Direct Yellow 28 as per the standard procedure followed by Trotman [5]

Table2. Treatment conditions of Desizing

Hcl (%)	Temperature(o°)
0.5	50
0.5	60
0.5	70

Table 3 . Treatment details (Chemicals , Temperature and dye shade)

NaCl (%)	Temperature(o°)	Dye Shade(%)
20	70	2
15	60	1
10	50	0.5

2.3 Testing

2.3.1 Conditioning of experimental materials

All the controlled and treated samples were conditioned at standard temperature of $27 \pm 2^\circ\text{C}$ and $65 \pm 2\%$ as per IS:6359-1971.

2.3.2 Determination of Geometrical Properties:

2.3.2.1 Determination of length and width of fabrics:

The length and width of the control and treated fabric samples were measured as per IS:1954-1969.

2.3.2.2 Determination of fabric set:

The parameter is defined the average distance between two consecutive threads in a fabric. Ends per inch and picks per cm is measured using densimeter as per IS: 1963-1969 and an average of 5 measurements are reported.

2.3.2.3 Yarn count

Yarn count (weight per unit length) was determined as per IS: 3442-1966. An average of twenty replications represented this parameter..

2.3.2.4 Fabric weight per square meter

The linear density in g/m^2 of the fabrics was determined as per IS: 1964-1970. An average of five measurements was expressed as weight per square metre.

2.3.3. 5 Determination of Fabric Compressibility /Thickness:

Fabric compressibility is measured using Shirley thickness gauze tester as per IS:7702-1975. The result shown is an average of at least 25 random measurements. EMC of control and treated Fabric Samples was determined using:

$$\text{EMC} (\%) = (T_o - T_m) / T_o \times 100 \quad \dots\dots (7)$$

Where T_o = No load thickness, T_m = thickness on load

2.3.4 Estimation of Percent Shift

In all the cases the percent shift was calculated using the formulae

$$\text{Shift} (\%) = (X_1 - X_2) / X_1 \times 100 \quad \dots\dots (8)$$

Where X_1 - value of control sample , X_2 - Value of Treated sample

3.0 Results

3.1 Step response of the Controller

The step response of the open loop system is obtained and the experimental data are shown in Table.1. From the step response of the open loop system, the transfer function model is obtained and is given by equation (7).

Table 4 Step response of the closed loop

Temperature($^\circ\text{C}$)	Time (secs)
50	73
51	80
52	93
53	116
54	132
55	177
56	203
57	292
58	379
59	472
60	559
60	573

60	593
60	623
60	653
60	693

The Ziegler-Nicolas Tuning Method is represented diagrammatically as below and the graph is plotted as follows which represent Time (T) and Lag (L):

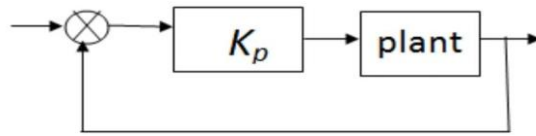


Fig.4 Diagrammatic representation of Ziegler-Nicolas Tuning Method

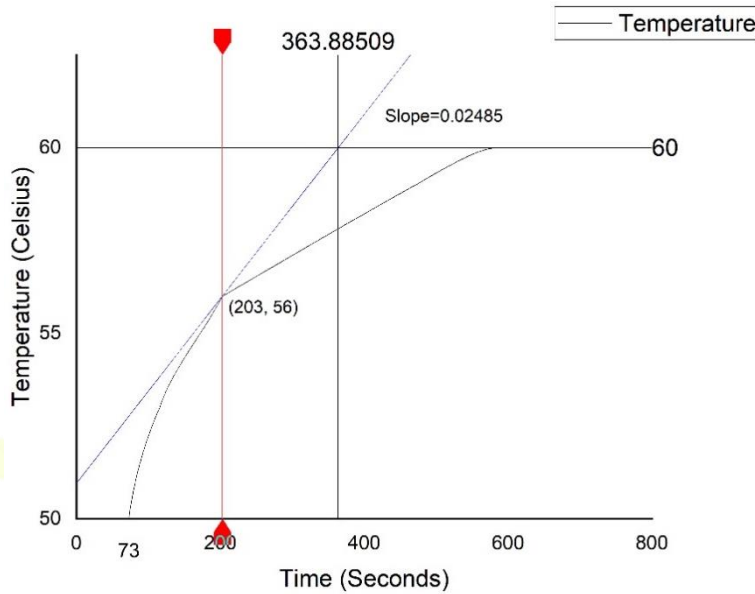


Fig.5 Graphical plot of T and L using Ziegler-Nicolas Tuning Method

The Ziegler-Nicolas Tuning formula to calculate the transfer function of the PID controller is represented below:

Table 5 Ziegler-Nicolas Tuning formula to obtain K_p, K_i, K_s

Controller type	From Step Response			From Frequency Response		
	K_p	T_i	T_d	K_p	T_i	T_d
P	$1/a$	-	-	$0.5K_c$	-	-
PI	$0.9/a$	$3L$	-	$0.4K_c$	$0.8T_c$	-
PID	$1.2/a$	$2L$	$L/2$	$0.6K_c$	$0.5T_c$	$0.12T_c$

The equation to find the transfer function,

$$G_c = K_p + \frac{K_i}{s} + K_d s \dots \dots \dots (8)$$

Thus, the transfer function G_c for the obtained values of K_p, K_i, K_s is

$$G_c = 0.438 + \frac{400}{s} + 100s \dots \dots \dots (9)$$

3.2 Effect of Desizing on the geometrical properties

Tables 3 show the effect of overall treatment on the geometrical properties of experimental samples .

Table 6 Changes upon overall treatment - % shift

Parameters	Sample 1	Sample 2	Sample 3
Count	-	-	-
Ends per cm	1.4	1.6	1.8
Picks per cm	1.1	1.2	1.3
length	0.8	0.9	0.98
width	1.3	1.45	1.56
weight	1.2	1.3	1.4

These results show the overall changes following treatment. Its clear from the Table 6 that change in the thread density changes the dimensions interms of percent shift and is a universally acceptable phenomena due to stress relaxation of the fabric following treatment .

3.3 Effect of Desizing on the fabric dimensions

Tables 7 to 10 show the changes in fabric dimensions following desizing . This is due to changes in the thread density for a given set of count and ends per cm , the fabric undergo stress relaxation as the fabric is under heavy tension during weaving in loom . The difference in the samples are due to change in picks per cm

Table 7 Changes in fabric dimensions upon desizing - % shift of **sample 1** with 0.5 % Hcl

Parameters	Desizing temperature thro'PID		
	50	60	70
length	4.16	3.35	2.99
width	3.56	2.62	1.98
weight	4.78	3.57	2.25

Table 8 Changes in fabric dimensions upon desizing - % shift of **sample 2** with 0.5 % Hcl

Parameters	Desizing temperature thro'PID		
	50	60	70
length	3.35	2.98	2.15
width	3.09	2.79	2.10
weight	4.55	3.88	2.96

Table 10 Changes in fabric dimensions upon desizing - % shift of **sample 3** with 0.5 % Hcl

Parameters	Desizing temperature thro'PID		
	50	60	70
length	12.04	10.49	9.9
width	6.95	5.63	4.58
weight	4.44	3.40	2.89

3.3 Effect of treatment on EMC

The compressibility of fabric following treatment was estimated as per the formulae given above and is recorded as in Table 11. Its clear that the value decreases as the thread density increases and this is due to higher cover and thus registering lower percentage of shift .

Table 11 Effect on Compressibility (%)

Sample 1	Sample 2	Sample 3
15	13.6	11.5

3.4 Effect of Dyeing temperature on fabric Weight

Tables 11 to 14 show the changes in the fabric weight as the dyeing temperature was changed using PID . The changes are due to the fact that as the temperature change the diffusion of the dye molecules also change and another strong reason for change in weight of the fabric sample is change in the exhausting agent like NaCl

Table 12: Changes upon Dyeing the sample 1,2,3 with direct dye at 70°C with 20% NaCl and 2% shade

Sl No.	Sample	Weight g (before)	Weight g (after)	% shift
1	G1	21	20.8	0.96
2	G2	1908	19.5	1.53
3	G3	15.7	15.6	0.66

Table 13: Changes upon Dyeing the sample 1,2,3 with direct dye at 60°C with 15% NaCl and 1% shade

Sl No.	Sample	Weight g (before)	Weight g (after)	% shift
1	G1	19.8	18.4	7.60
2	G2	20.82	18.6	11.93
3	G3	15.96	16.0	-0.25

Table 14: Changes upon Dyeing the sample 1,2,3 with direct dye at 50°C with 10% NaCl and 0.5% shade

Sl No.	Sample	Weight g (before)	Weight g (after)	% shift
1	G1	19.93	19.86	0.35
2	G2	20.82	21.9	-4.93
3	G3	16.05	15.5	3.54

4.0 Conclusions

The study show clearly the role of temperature as controlled by PID .Textile dyeing is one of the important textile wet processing and any attempt to save thermal energy is most welcome aspect. By using PID it was understood that the temperature can be positively controlled and thus the saving in thermal energy can be achieved. . In industry heat exchangers are used and if PID is employed the temperature can be controlled to a factional value also . A lot of scope exists for continuation of the present study.

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