A MATHEMATICAL MODEL OF WOOL FOAM LOW TEMPERATURE DYEING

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INTRODUCTION

In the foam dyeing process the amount of water that is used is much lesser than in the classical dyeing processes, and consequently the volume of wastewater is also smaller.

The foaming capacity of the dyeing solution is determined by the presence of surfactants. There are proves that wool dyeing in the presence of surfactants might be performed at low temperature (about 80^{o}C) [1 - 6]. A foam dyeing process that is conducted at low temperature would have the benefits of both processes, hence less wastewater, energy consumption and fiber damage [7]. In this case of particular interest is the way process parameters influence the quality of the dyeing. This study investigates the possibility to obtain high quality in the foam dyeing of wool at a temperature below 80^{o}C by establishing a mathematical model of the process.

1. EXPERIMENTS

In the experiments scoured wool was used. The dyestuff that was tested was Acid Red 17, C.I. 16180. The dyeing was performed in an apparatus that allows the continuous feeding with foam. The apparatus is formed of a flask that contains the foaming solution, in which air is blown. The foam that is formed rises in the flask and enters in the superior flask, where the wool to be dyed is placed. In this way the wool is kept permanently under foam. The liquid that is produced from the breaking of foam and the foam that exceeds the top of the superior flask are pouring in the inferior flask were the foaming liquid was initially placed.

The foaming agents that may be used are of anionic type. The sketch of the dyeing apparatus is presented in fig. 1.

In previous work, we have established that the best recipe for the dyeing solution to be foamed contains as foaming agent Romopal O, in concentration between 0,3 and 0,5 g/l and a temperature of the solution higher then 75^{o}C. In order to establish the technological parameters that allow best dye uptake we realized a mathematical model of the process. The dyeing has been realized in the following conditions: 3% dyestuff, 3% acetic acid, 3% sodium sulfate, foaming agent - variable concentrations, volume of the solution to be foamed - 25 ml, weight of the wool that is dyed - 5 grams, air flow rate - 2 litter/minute, variable temperature of the foamed solution, dyeing time 60 minutes.

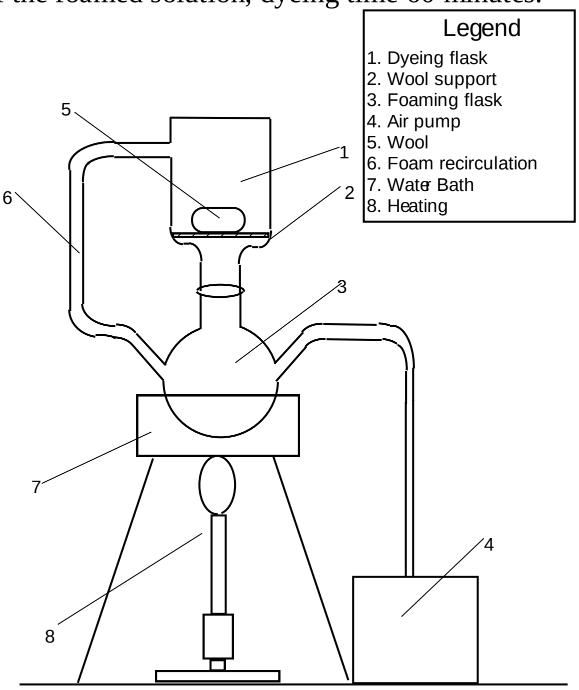

Figure 1.

To ascertain the mathematical model a two independent variable rotable central composed program has been used [8]. The independent variables that have been chosen were:

x_1 - surfactant concentration, in g/l;

x_2 - temperature of the foamed solution, in ^{o}C;

The codification of the parameters is shown in table l.

Table 1. Codification of the independent variables.

Code	-1,414	-1	0	1	1,414
Surfactant concentration, g/l	0,2	0,244	0,35	0,456	0,5
Temperature, ^{o}C	70	72,9	80	87,1	90

The dependent variable that we have used was the uptake of the dyestuff; that was determined spectrophotometrically using the solution that resulted when extracting the dye from the dyed fiber (the extraction was performed with pyridine).

The regression equation that was obtained is:

$$\mathbf{Y = 28{,}105 - 1{,}104 \cdot x_1 + 1{,}323 \cdot x_2 - 0{,}368 \cdot x_1^2 - 5{,}616 \cdot x_2^2 + 0{,}102 \cdot x_1 \cdot x_2.}$$

We tested the parameters of the regression equation using Student test. We compared the calculated values (table 2) with the tabled value for the test ($\propto$=0,95 and ν=4), that is 2.132.

Table 2.

Tb_0	215,559
Tb_1	-10,706
Tb_2	12,837
Tb_{11}	-3,326
Tb_{22}	-50,799
Tb_{12}	0,673

It can be seen that five of the analyzed coefficients have a calculated value bigger than the tabled one. That signifies that they have an effective influence upon the dependent variable.

In conclusion, regression equation has the following form:

$$\mathbf{Y = 28{,}105 - 1{,}104 \cdot x_1 + 1{,}323 \cdot x_2 - 0{,}368 \cdot x_1^2 - 5{,}616 \cdot x_2^2}$$

The critical point of this function (which is a maximum one) has the following coordinates (codified values): $x_1 = -1{,}391$ and $x_2 = 0{,}118$. The real values that correspond to these codified values are: a concentration of surfactant of 0,225 g/l and a dyeing temperature of 80,7°C. The value of the dependent variable obtained in this point is of 29,011. We used three tests for evaluating the correctness of the mathematical model and each of them confirmed that the equation models well the process.

2. RESULTS AND DISCUSSIONS

Analyzing the regression function it can be seen that the independent variables have an almost equal influence upon the dye uptake; nevertheless, the second has a bigger influence (the coefficient of x_2 is 1,323 and the coefficient of x_1 is 1,104 in modulus). When the first independent variables increases, the dye uptake decreases, while the increase in the value of the second independent variable determines an increase in the value of the determined variable.

Fig. 2 presents the variation of the dye uptake with both independent variables. It can be seen the maximum point, and the fact that the influence of the temperature of the foamed solution is important.

The way each of the independent variables influence the dye uptake when the second independent variable is maintained constant and equal to zero (codified value) is showed in fig. 3. One can observe the existence of a maximum point at a value of x_1 equal to 0,2 (the uncodified value is of 81°C). The influence of the concentration of the foaming agent is of lesser importance, as one can observe the slight decrease of the dye uptake.

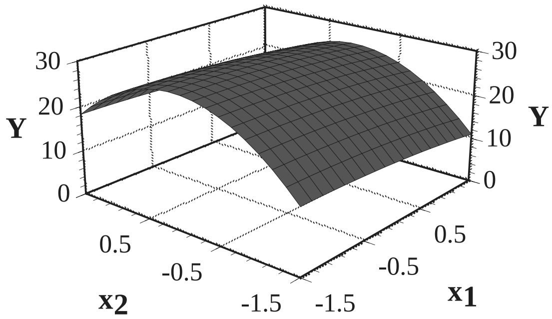

Figure 2.

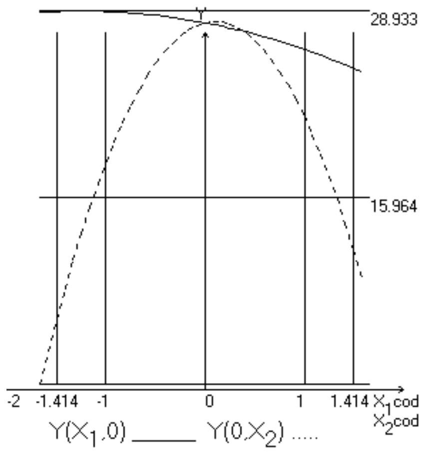

Figure 3.

In figures 4 and 5 it is showed the variation of the dye uptake in correlation with both the independent variables when the second independent

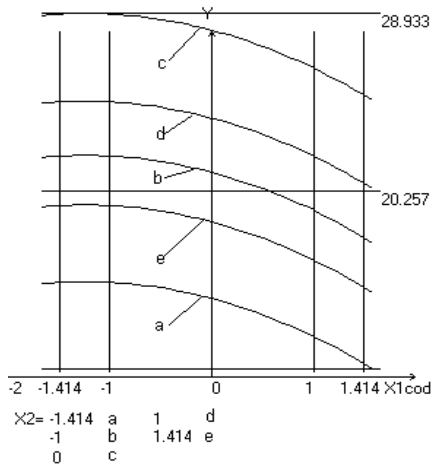

Figure 4.

variable is maintained constant for all the five significant values.

From fig. 4 it can be observed that the shape of the curves is practically identical for all the five values of the x_2 variable, but the values of maximum vary largely. The maximum values increases in the order a<e<b<c<d, hence best results are obtained at a temperature of the foams solution of around 80°C.

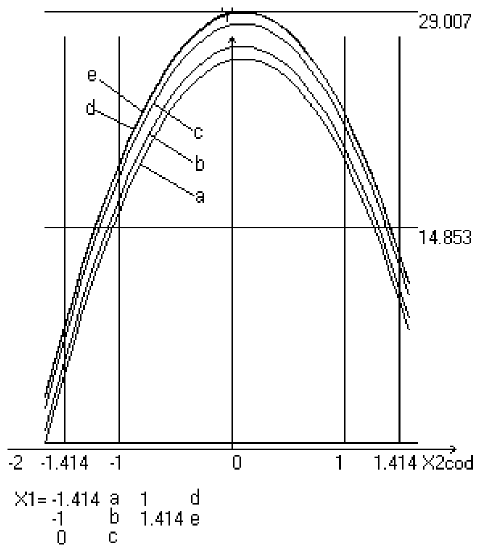

Figure 5.

From fig. 5 it can be seen that the shape of the curves is similar. In this case best results are obtained when x_1 varies in the range of values between - 1,414 and -1.

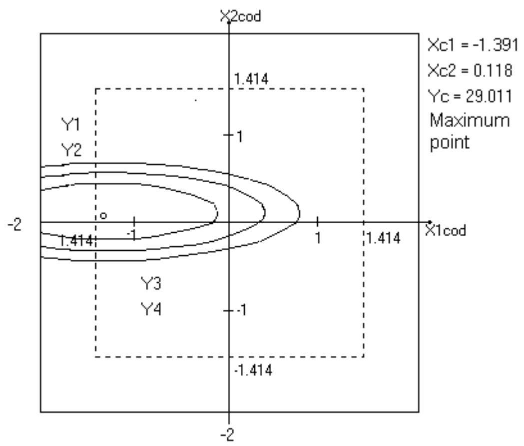

Figure 6.

The curves obtained for constant values of the dye uptake between 29,5 (Y_1) and 27,5 (Y_5) (fig. 6) allow the precise determination of the coordinates of the maximum point. These are $x_1 = –1,391$ and $x_2 = 0,118$. The real values that correspond to these codified values are 0,225 g/l for the de Romopal O concentration and 80,70°C for the temperature of the foamed solution. The correspondent value of the dye uptake is 29,01 mg/g.

3. CONCLUSIONS

The mathematical model of the foam low temperature dyeing of wool allowed us to emphasize the big importance that the temperature of the foamed solution has upon the dye uptake. It has been concluded that best results are obtained at a temperature of 80,7°C, upper values determining modest characteristics of the foams.

The role of the foaming agent concentration is of less importance, but even in this situation has been determined a value that allows the obtaining of best results: 0,225 g/l foaming agent.

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