INTENSIFICATION OF RIPENING OF VISCOSE WITH THE AID OF AN OPTIMIZATION EQUATION FOR THE PROCESS

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Among the stages of the technological process of obtaining and preparation for manufacture, the ripening of viscose takes a particularly long time. The time of stay of spinning solution in the viscose cellar is 60-70% of the total time for the whole operation carried out in the chemical plant.

In recent years all the stages of the process preceding ripening and also the drying of the viscose have been considerably intensified by improvement of the technology and design of apparatus.

However, for a satisfactory solution to the problem of the intensification of the technological process of obtaining spinning solution we require a severe reduction in the duration of ripening. This problem can be solved, for example by increasing the ripening temperature. But it is difficult in practice then to keep the degree of ripeness of the solution entering into the formation constant. For the intensive progress of the process it is necessary for there to be a very high accuracy of the maintenance of the period of ripening and delivery of viscose into forming.

The above difficulty can be overcome if at the end of the process viscose is obtained with not only a certain ripeness but also a sufficiently low production of it with time, i.e., the reaction is slowed down at the moment when a certain ripeness is obtained. The low thermal conductivity and large heat capacity of viscose considerably complicate the problem.

The optimum conditions of variation in the temperature of the solution to ensure obtaining viscose with a definite ripeness and its production with time (sufficiently low), in the shortest time, can be found with the aid of mathematical optimization methods. We have carried out below a solution of the problem discussed with the aid of the Pontryagin "optimization principle".

Mathematical Model of the Process

The main chemical reaction occurring in the ripening of viscose is the hydrolysis of xanthate which is accompanied by a decrease in the degree of its esterification, $\gamma$. The kinetics of the dissociation of cellulose xanthate is characterised by a system of two first-order differential equations, which is caused by the presence of two kinds of thiocarbonate groups possessing different stabilities [1-3]. Thereby the main process (excluding the initial period of ripening, precipitating from under control by means of ammonium chloride - "perpetual" ripening) is the cleaving of thiocarbonate groups at a single carbon atom.

The predominance of one of the reactions is so significant that some investigators find it possible to represent ripening kinetics by a single equation of the first order [2]. Under the conditions of our problem this is all the more permissible since the control of the ripening of viscose is required before manufacture, after a stage of solution, blending and filtration, as a result of which the xanthate is already partially hydrolysed. The ripening kinetics can be expressed by the equation

$$\frac{d\gamma}{dt} = -K(T)\gamma ,$$

where $\gamma$ is the present value of the degree of esterification; $K(T)$ is a rate constant depending on the temperature; $t$ is the duration of ripening.

The dependence of the rate constant on temperature obeys Arrhenius' law [3] which in a limited temperature can be simplified by linearisation in the exponential $e$:

$$K \approx K_v e^{\beta\Theta}$$

\[ K_1 = K_0 e^{-E/RT}, \quad \beta = \frac{E}{RT} , \]

where \( E \) is the activation energy; \( R \) is the gas constant; \( \theta \) is the temperature deviation from a certain arbitrary value \( T_0 \); \( K_0 \) is a constant.

The error as the result of the approximation to Arrhenius' law does not exceed 2\% on changing the ripening temperature within the range from 10 to 45°C.

Let us assume that the dynamic properties of the heat channel, by which control of ripening is achieved, may be written by the first-order equation

\[ a_0 \frac{d\theta}{dt} + a_1 \theta = bu , \]

where \( u \) is the controlling influence, determining the intensity of heating (cooling) of the viscose; \( a_0, a_1 \) and \( b \) are constant coefficients.

The viscose ripeness \( \gamma \) and the rate of its change \( dy/dt \) we designate respectively as \( X_2 \) and \( X_1 \). We assume that these values are known at the start of control of ripening \((X_{1i}, X_{2i})\) and given at the end of the process \((X_{1f}, X_{2f})\). The following limits are put on the controlling influence:

\[ 0 \leq u \leq U \cdot \]

Substituting in Eq. (1) and eliminating the temperature \( \theta \) from Eqs. (1) and (3) by means of Eq. (2) we obtain a mathematical model of the object in the final form:

\[
\begin{align*}
\frac{dX_1}{dt} &= X_2, \\
\frac{dX_2}{dt} &= \frac{X_1^4}{X_2^4} - \frac{a_2}{a_1} X_2 \ln \left( \frac{X_2}{K_1 X_2} \right) + \frac{b b}{a_1} X_2 u \]
\end{align*}
\]

\[ X_1(0) = X_{1i}; \quad X_2(0) = X_{2i}; \quad X_1(t_f) = X_{1f}; \quad X_2(t_f) = X_{2f} \]

\[ 0 \leq u \leq U \cdot \]

This non-linear system of equations contains as variables only the co-ordinates of the object \((X_1, X_2, \text{ and direction } u)\).

**Calculation of the Optimum Conditions of the Ripening of Viscose**

It is necessary to choose such an acceptable control \( u(t) \), so as to transfer the object, whose motion is represented by system (5), from the initial state \( X_{1i}, X_{2i} \) to a given final one \( X_{1f}, X_{2f} \) in the shortest time. After the method of "maximum principle" [4], we create a function \( H \):

\[ H = \psi_1 X_2 + \psi_2 \left[ \frac{X_1^4}{X_2^4} - \frac{a_2}{a_1} X_2 \ln \left( \frac{X_2}{K_1 X_2} \right) + \frac{b b}{a_1} X_2 u \right], \]

where \( \psi_1 \) and \( \psi_2 \) are time functions of the system, conjugated with regard to the system of Eq. (5).

The function \( H \) attains its maximum value if the direction \( u \) has an optimum value as regards the duration of the process [4]. It is not difficult to see that the function \( H \) attains a maximum, providing

\[ u(t) = \frac{U}{2} - \frac{U}{2} \text{sign} \psi_2 , \]

since at all times \( X_2 = 0 \); \( \text{sign} = \pm 1 \) (in accordance with the sign of \( \psi_2 \)).

Thus the equation has a reversible character, taking successive limiting values (maximum and minimum) depending on the sign of the function \( \psi_2(t) \). The problem consists of determining the number and moments of the reversing equation. Meanwhile it is possible to avoid the exceptionally complex and cumbersome operation of finding \( \psi_2(t) \) by the joint solution of the system of equations (5), Eq. (7) and the conjugate system of equations.

In accordance with problem initially formulated, intensification of the process consists of shifting it into the high temperature conditions. Consequently in the first period the control should take a maximal