Computer Control of Soaking Process

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Abstract: - The paper deals with application of automatic control via microcomputer technology in leather manufacturing industry. Processing of raw hides comprises a series of particular processes through which raw hide is progressively transformed into the product usable for the production of leather goods which are part of our everyday life. Our contribution is focused only on one problem - the particular process of soaking, in which the input raw material can be irreversibly damaged in case of failing to abide the necessary low concentration gradient. The automatic control system working on the knowledge of mathematical model of physical-chemical processes present in the input raw stock is able to fulfill this condition and thus to secure the quality of the final product.

Key-Words: - manufacturing technology, mathematical model of a system, measuring and control microcomputer system, simulation.

1 Introduction

Leather is manufactured from animal hides by the process which, besides others, also comprises tanning, preservation and subsequent desalting before it is used for final products. This process is not only energy-intensive, but also consuming from the viewpoint of raw materials. Increasing prices of energies, chemicals and water as well as problems related to environmental issues require rationalization and optimization in the industry. Therefore it is a common practice nowadays to endeavor optimization and control of every single process in order to increase their efficiency and minimize the necessary costs.

Between flaying and further processing of the hide there is usually a time period necessary for storing and transport. In this time period, the enzymatic system of skin liquids and microbial action lead to decomposition of hide proteins and deterioration of their properties. For these reasons raw hides must be preserved. The most common ways of preservation are solid salt, brine solution or pickling.

Cured hides are delivered to tanneries in partially dewatered state, or even completely dried. Therefore it is necessary in the first place to soak the hides and remove salt they have been preserved with. The soaking operation takes place in big drums. Except for the modern drive of the engines, this way of soaking has been used for more than one hundred years [Covington, 2009].

One of the following three ways is used in the desalting operation [Covington, 2009]:

1. Flow system, where plain water is continuously brought to rotating drums. The increase in the water level is compensated by the outflow of waste water. The advantage of this way lies in the permanent contact of hide with clean water, which accelerates the desalting process. A disadvantage is high water consumption.
2. Decantation washing, where hide is washed with plain water in several steps. In this case it is always necessary to wait until equalization of the salt concentrations in the hide and washing bath. This way is very time-consuming, but on the other hand requires much less plain water than it is in the previous case.
3. The last way consists in waste water utilization in the subsequent steps of the washing process. The only waste then is water saturated with salt from the last step of decantation washing. This system can reduce water consumption by 150% in each washing step [Kaul et al., 2005]. The hides are hydrated until they reach the state of fresh hides after flaying. The process of hide tanning, soaking and desalting is one of the most water-consuming industrial processes [Kaul et al., 2005]. Approximately 15-80m^3 of water is consumed per one ton of raw hide, giving in the outcome about 250kg of usable leather [Orhon, 2009].

During the soaking operation the hide is soaked in plain water. This results in great concentration shocks on the surface and the inner structure of the cured hide. Plain water causes enormous concentration gradient of salt on the hide surface leading to irreversible damage of the hide structure. For this reason it is advantageous to control the soaking operation in the sense of maintaining sufficiently low concentration gradient and thus securing the final product quality.

Up to the present time, the control of soaking has been based mostly on empiric experience. There have been rare attempts to quantitatively describe the process. This contribution deals with the soaking operation control based on the knowledge of processes taking place inside the hides. By a suitable regulation of plain water flow rate it is possible to achieve gradual decrease in salt concentration in the washing liquid; thus, salt concentration in the hide decreases evenly in the entire profile of the processed raw material.

2 Theory

Before the solving itself it is important to describe the system behavior with the use of a mathematical model. Proceeding from Figure 1, the model of soaking using plain water flow can be described by the following diffusion equation

$$\frac{D\partial^2 c(x,\tau)}{\partial x^2} = \frac{\partial c(x,\tau)}{\partial \tau}$$

By introducing dimensionless variables we get

$$-\frac{\partial C(X,F_0)}{\partial X} = L[C_0(F_0)+1] + \frac{N_a}{\varepsilon}\frac{\partial C_0(F_0)}{\partial F_0}$$

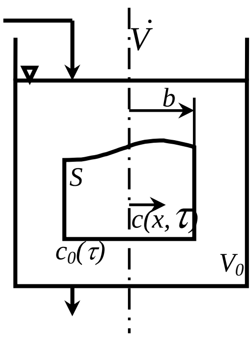
where the dimensionless quantities have the form:

$$X = \frac{x}{b} \qquad F_0 = \frac{D\cdot\tau}{b^2} \qquad N_a = \frac{V_0}{S\cdot b}$$

$$L = \frac{\dot{V}\cdot b}{S\cdot D\cdot\varepsilon}$$

$$C = \frac{c-\varepsilon\cdot c_{0p}}{c_p} \qquad C_0 = \frac{\varepsilon(c_0 - c_{0p})}{c_p}$$

The initial concentration value is $C(X,0)=0$.



τ – time

b – maximal sample thickness

x – variable sample thickness

S – sample surface area

c – salt concentration in the sample

c_0 – salt concentration on the sample surface

V_0 – bath volume

Fig. 1a. Through-flow soaking model

The solution for the through-flow systems is

$$C(X,F_0) = -1 + 2L\cdot \sum_{n=1}^{\infty} \frac{\cos(X\cdot q_n)e^{(-F_0\cdot q_n^2)}}{q_n\sin(q_n)+q_n^2\cos(q_n)+q_nL\sin(q_n)+\frac{2N_a q_n^2\cos(q_n)}{\varepsilon}-\frac{q_n^3 N_a\sin(q_n)}{\varepsilon}}$$

The roots q_n can be calculated from the transcendent equation

$$tg(q_n) = \frac{L}{q} - \frac{N_a}{\varepsilon}q$$

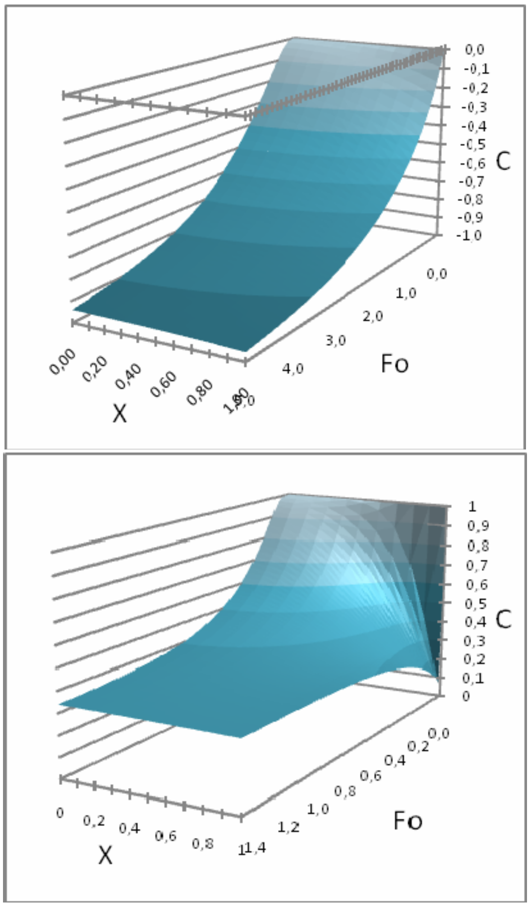


Fig. 1b. Concentration field of the through-flow system for L=2(above) and a stationary system (below)

Fig. 2 shows comparison of concentration fields for a through-flow and stationary system. It is obvious from the graphs that there are significant changes in salt concentration inside the hide; this negatively affects the resulting hide quality after desalting. In the through-flow system, the difference between salt concentration on the surface and inside the hide depends on the flow rate. The faster the plain water flow rate is the bigger difference in salt concentrations. Therefore for the system control it is necessary to direct the gradient of concentration decrease so that the differences between salt concentration on the surface and inside the hide were low enough.

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3 Control algorithm

The plain water flow rate control is based on maintaining concentration gradient of salt in the washing bath. The information on concentration changes is obtained from a conductivity sensor. The algorithm requires setting of several parameters depending on the operating conditions (washing bath volume, character and kind of the hide and the required concentration gradient which is to be maintained by the algorithm). The setting namely concerns the following parameters:

1. Setting the sampling period
   a. Setting the period for control action (T) calculation
   b. Setting the reading period for the conductivity value T_R
2. Minimal and maximal flow rate value
3. Required gradient of concentration decrease

The sampling periods are mutually dependent according to the following equation

$$T_R - \frac{T}{4}$$

The algorithm works on the principle of the system future behavior estimation. From the previous control action, the required value and the output value is calculated the value of control action in the next step. The sampling period should be set in such range to detect the reaction to control action. In other words, the system delay should be smaller than the sampling period.

Control action is calculated according to equation

$$u_k = \frac{w \cdot u_{k-1}}{y_k} \cdot K$$

where w is the required gradient value, u_k is the current control action, u_{k-1} is the previous control action, y_k is the current gradient value calculated from five previous conductivity values and K stands for amplification factor which compensates the time delay.

4 Simulation confirmation

To avoid the initial concentration shock it is necessary to start the washing process in the bath with a higher salt concentration. This will prevent a sudden and damaging concentration shock on the hide surface.

For the simulations we used the soaking model described in the theoretical part. Unlike in experimental measurements, dimensionless quantities were used. Fig. 3 depicts the entire control process for the required gradient of -0.5. The entire simulation time reaches approximately 13.5 hours for a good shape hide (with diffusion coefficient of $D=10^{-9}m^2s^{-1}$) 8mm in thickness. It is evident from the figure that the gradient gradually decreases within the whole thickness of the hide.

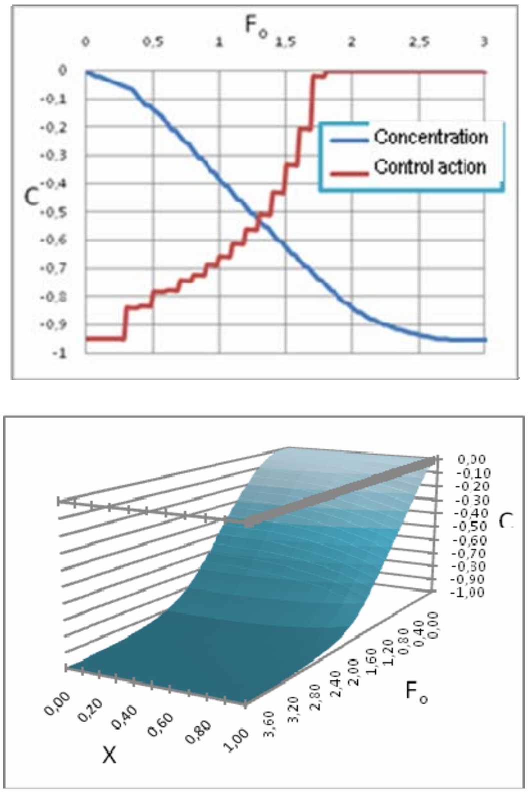

Fig. 2 Simulation of desalting process control and the corresponding concentration field

A maximal difference between salt concentration on the surface and the inner hide structure (ΔC=0.184) occurred in control simulation in the time of F_o=1.3. The flow rate was regulated gradually from the minimal flow rate of L=0.5 up to the maximal one L=10. The resulting dimensionless time after desalting is around 3, which corresponds to approximately 14 hours for a hide in good shape. At constant flow rate of L=2 the concentration difference between the hide surface and the inside in the time F_o=0.6 was ΔC=0.213. Furthermore, the entire desalting process took more than 5 units of Fo. This corresponds to more than 23 hours. The desalting time can be reduced to F_o=3 at constant flow rate, but this is at the cost of concentration difference of ΔC=0.384, which is twice as high in comparison with regulated flow rate.

5 Experiment

The simulations were further verified on a real experimental model controlled by 16bit microcomputer 9S12NE64. The connection between the operator and the model was run via an Ethernet interface and web server implemented directly in the

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microcomputer.

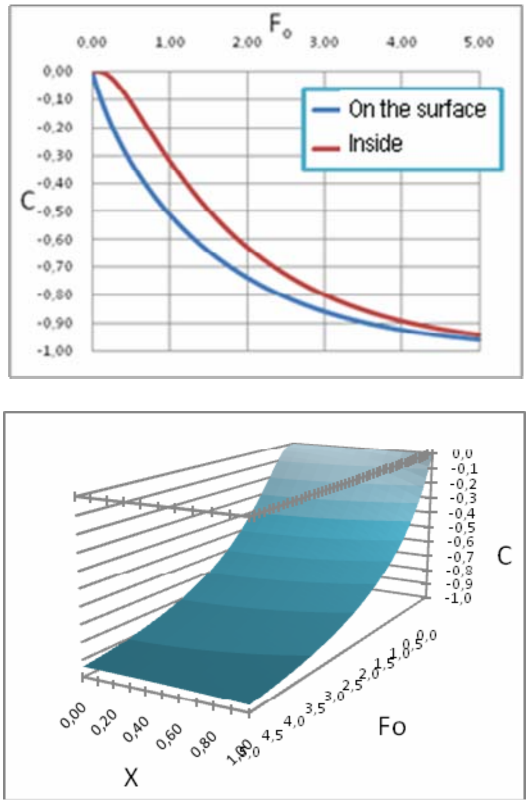

Fig. 3. Concentration course and concentration field in control simulation for constant flow rate of *L*=2

Fig. 5 (above) depicts the conductivity courses for various flow rates. Fig. 5 (below) shows the course of a real control on an experimental model. Figures 3 and 5 confirm close similarity between the behaviors of the simulation and real experiment.

5. Conclusion

A control algorithm has been proposed for the process of raw hide desalting. For the solution we selected a flow system with automatic control of plain water flow rate. The problem solution depends on inner processes which take place in the hide during desalting. This approach secures maintaining the hide quality since it provides even and sufficiently low decrease in salt concentration. This helps to prevent so called concentration shock that devalues the final product quality. The solution is usable in leather industry and optimizes the process from the viewpoint of maintaining the quality of desalted hides. The asset of our approach is that the control algorithm is based on the technological process quantitative description. Further, the proposed algorithm can be applied in a variety of other processes that show similar characteristics as the soaking process.

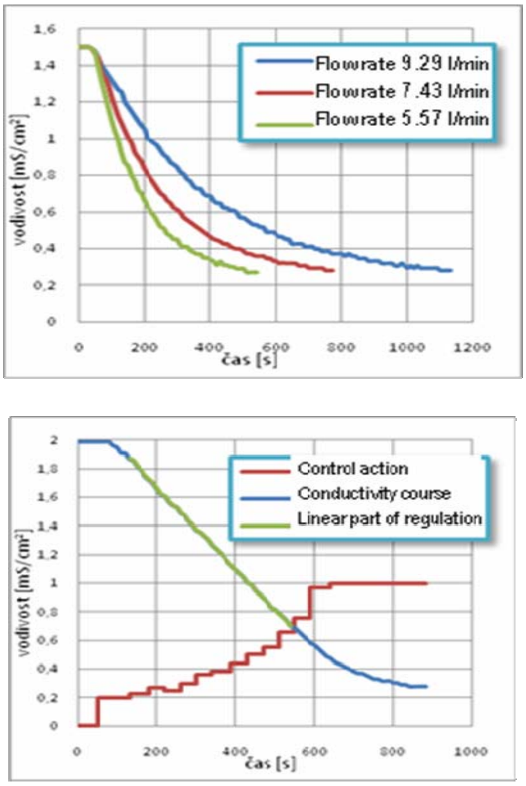

Fig. 4. An overview of the conductivity course for various flow rates (above), control for the required gradient -0.003(below)

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References:

[1] COVINGTON, D. A., (2009). *Tanning Chemistry: The Science of Leather*. RSC Publishing, Cambridge, 2009. ISBN 978-0-85404-170-1

[2] CRANK, J. *The Mathematics of Diffusion*, 2nd Ed. Clarendon Press, Oxford 1977. ISBN 0-19-853411-6.

[3] KAUL, S. N., NANDY, T., SZPYRKOWICZ, L., GAUTAM, A., KHANNA, D. R. (2005). Waste Water Management With Special Reference to Tanneries. Discovery Publishing House, New Delhi, 2005. ISBN 81-7141-918-6

[4] KOLOMAZNÍK, K., PROKOPOVÁ, Z., VAŠEK. V., BAILEY, D. G. (2006) Development of a Control Algorithm for the Optimized Soaking of Cured Hádes. The *Journal ot the American Leather Chemists Association*. Volume 101/9, 2006, pages 309-345.

[5] ORHON, D., BABUNA, F. G., KARAHAN, O. (2009). Industrial Wastewater Treatment by Activated Sludge. IWA Publishing, London, 2009. ISBN 1843391449

[6] Motorola. MC68HC11A8 HCMOS single-chip Microcontroller, 1996. Available from WWW: <www.freescale.com>