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OPTIMIZATION OF WASHING OF BOUND COMPONENT FROM WHITE HIDE

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Abstract

In this paper, we focused on optimizing processes that minimize the consumption of water, electricity, and auxiliary chemicals. An indirect mathematical-physical deterministic model based on mass balance can be used to optimize the process. It is a diffusion process characterized by the diffusion coefficient and the fixing power of the washed component to the white hide after deliming process. These parameters belong to the input data, which are further used for the application of automatic process control.

Keywords: Mathematic modelling; optimization; wash process; washing of bound component.

1. Introduction

Many technological processes are characterized by a large consumption of water, electrical energy, and auxiliary chemicals. Neither the tanning industry is the exception. The contemporary worldwide trend is an application of cleaner production principles, which means to take the line of savings and minimization of waste production. It is necessary to deal with the optimization of processes [1]. In our work, we concentrated on the optimization of washing processes in tannery industry because they are included in many technological processes, namely several times in some cases The achieved saving can be considerable, and this is the reason why to deal with this. The purpose of the washing process is to wash out the undesirable components from solid phase by water in which the washed component is very well soluble or partly soluble. If it is partially soluble it is necessary to determine the optimum amount of washing water. The insoluble part makes no sense to wash it with clean water. On the other hand, clean water is a cheaper detergent than chemicals. The aim of this work is to determine the minimum cost of the process of washing lime from white hide.

Depending on the arrangement, the washing processes can be divided into several cases: washing the bound or unbound components from the washed raw material. Each case is further divided into bath, decantation, flow arrangement[2]. After the deliming operation, it is important to make a pure water wash to remove lime residues (Fig.1). The deliming and washing process we had described by diffusion model which gives the answer to the above mentioned question.

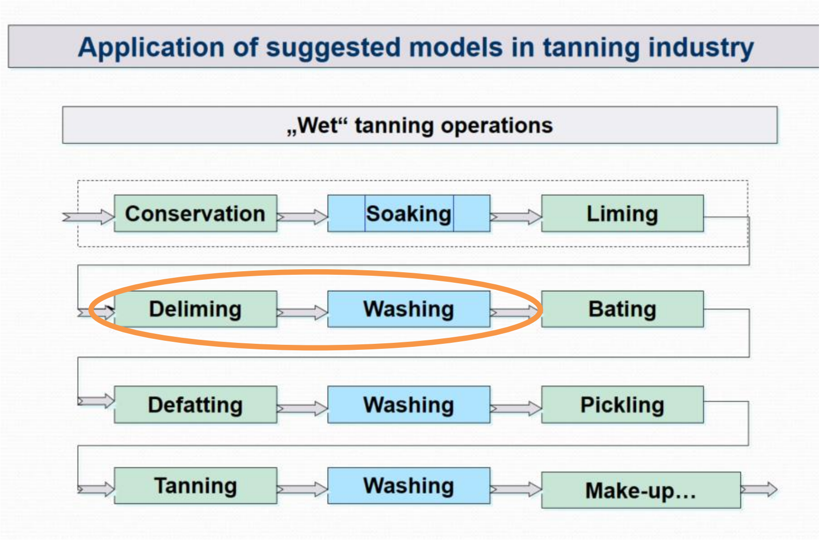

Fig. 1. The scheme of operation of tannery technology [11]

The quantitative description is based on the mechanism, the individual methods of adjusting the washing process, and is based on the mass balance of the eluted component.

2. Mathematic model of the one-step washing process after the deliming process

For the next procedure of the washing process rationalization, it is substantial in which part of the sorption isotherm a state of washed component can be found. Based on Fig.2, it is the state *C* or *B*. In the area of state *C* the washed component is free (does not bind); in area *B* the washed component is bound to solid phase [4]. In this area it is also possible to delimitate zone A, in which the sorption dependence is practically linear [2, 3]. The constant of proportionality (equilibrium constant of sorption) characterizes the strength of linkage to solid phase, i.e. largely it can determine how the washing process is effective in this area. In the simplest case it is possible to express this dependence by Langmuir sorption isotherm.

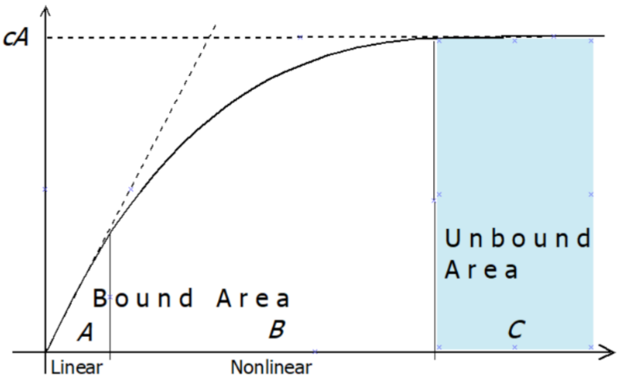

Fig. 2. Langmuir´s sorption isotherm

The easiest possibility of the sorption constants setting A, B of Langmuir isotherm is directly used in its quantification [5].

$$c_A = \frac{Kc}{Bc+1} \tag{1}$$

This procedure needs relatively precise setting, both solid and liquid phase. However, the setting of lime concentration in hide can cause complications. On this account was designed the indirect method only incumbent in analyze of liquid phase. To this purpose can be derived dependence. For very small values c is possible product B.c in relation (1) vanish on 1, it means 1 >> *B.c* [6]. Then can be written

$$c_A = K \cdot c \tag{2}$$

Where we set off the exact value of constant A on nonlinear relation (1) and approached it by constant value *K*, from linear relation (3), it means that here valid $K \approx A$. In this process, the white hide is put into the washing liquid. The washing liquid flows neither in nor out of the bath. Under assumptions that lime content in hide. lt is lower than its solubility in the same volume of washing liquid at the given temperature, and the influence of flanges on diffusion inside of the hide sample is neglectable can formulate a one-dimensional model of bath washing of hide sample by diffusion model of transport of washed-out lime [7].

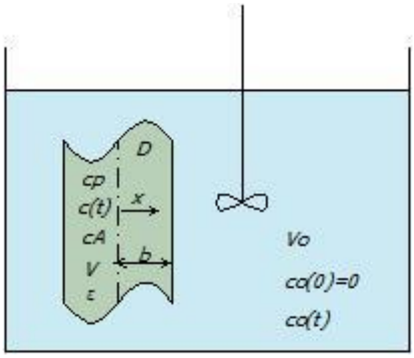

Fig. 3. The one-step washing process after the deliming

Under assumptions that component content in hide is lower than its solubility in the same volume of washing liquid at the given temperature and the influence of flanges on diffusion inside of the hide, the sample is neglectable can formulate one-dimensional space-model of bath washing of hide sample by diffusion model of transport of washed component

$$\frac{D}{A+1} \cdot \frac{\partial^2 c(x,t)}{\partial x^2} = \frac{\partial c(x,t)}{\partial t}, \qquad t > 0, \quad 0 \le x \le b \tag{3}$$

$$c(x,0) = c_p \tag{4}$$

$$c_0(0) = 0 \tag{5}$$

$$c(b,t) = \varepsilon c_o(t) \tag{6}$$

$$\frac{\partial c}{\partial x}(0,t) = 0 \tag{7}$$

$$\frac{\partial c}{\partial x}(b,t) = -\frac{V_0}{D \cdot S} \cdot \frac{\mathrm{d}c_0}{\mathrm{d}t}(t) \tag{8}$$

The equation (3) represents component ions diffusion from material in the direction of washing liquid bath. The expression of the right-hand side last term of equation depends on desorption mechanism of the washing component from solid phase [12]. If we suppose that diffusion is determining for change rate of concentration, then it is possible to express the dependence of bound component c_A on the unbound component *c* by the relation of Langmuir's sorption isotherm [5].

Condition (4) shows the initial distribution of calcium ions concentration in a white hide. Relation (5) describes that we use pure water for material bath washing. Relation (6) holds under the condition of a perfectly mixed liquid phase. Boundary condition (7) denotes that the field of concentration in solid phase is symmetric. Boundary balance condition (8) denotes the equality of the diffusion flux at the boundary between the solid and the liquid phases with the speed of accumulation of the diffusing element in the surrounding. We introduce dimensionless variables for the solution of equation (9).

$$C = \frac{c}{c_p}, \; C_0 = \frac{c_0}{c_p}, \; F_o = \frac{D \cdot t}{b^2 \cdot (1+A)}, \; X = \frac{x}{b}, \; Na = \frac{V_0}{V}, \tag{9 a,b,c,d,e}$$

By mean of Laplace transformation, we obtain an analytic solution. The final solution is given by dimensionless concentration field $C(X,F_o)$ in a material.

$$C\left(X,\ F_o\right) = \frac{\varepsilon\ (1+A)}{\varepsilon\ (1+A)+Na} - 2\ Na \cdot \sum_{n=1}^{\infty} \frac{\cos\ (q_n X)\ \exp(-q_n{}^2 F_o)}{\varepsilon(1+A)\ \cos\ \left(q_n\right) - \dfrac{\varepsilon\ (1+A)}{q_n}\ \sin\ \left(q_n\right) - Na\, q_n \sin\left(q_n\right)} \tag{10}$$

where q_n is the n-th positive root of the following transcendent equation

$$-\frac{Na \cdot q}{\varepsilon \cdot (1+A)} = \tan(q) \tag{11}$$

2.1 Determination of the effective diffusion coefficient

The theoretical value of the diffusion coefficient of the calcium component can be calculated from the Nernst equation, which is valid for electrolytes at infinite dilute [9].

$$D_o = 8.931.10^{-10} T \left(\frac{l_+^o . l_-^o}{\Lambda^o}\right) . \left(\frac{z_+ + z_-}{z_+ . z_-}\right) \tag{12}$$

In the case of small concentrations and very small diffusion coefficients, we can assume that the concentration profile of a layer where washing was done is linear [8]. We can then approximately evaluate the diffusion coefficient of component from equation (12), which is valid for the washing.

Measurement no.10		*t [s]*	$\sqrt{t}$ *[s$^{-1/2}$]*	c_0 [g/ml]	$\frac{c_0}{c_p} \cdot 10^3$
Dry matter	*40 [%]*	300	17,3	21,34	4,21
Thickness	*0,005 [m]*	600	24,5	34,63	6,78
Weight	*0,107 [kg]*	1200	34,6	51,07	9,99
Bath capacity	*0,00016 [m3]*	1808	42,5	61,56	12,05
Surface of hide	*0,0229 [m2]*	2410	48,9	62,61	12,25
Bath temp.	*25 [°C]*	3000	54,8	58,07	11,36
Porosity ε	*0,5* -	3600	60	78,71	13.99
***Type of hide**: Cowhide. USA Packer , over fleshed, Weight class 56/67*		4203	64,8	76,61	14,50
		4800	69,3	77,31	15,13
		5400	73,5	79,05	15,47

Table 1. Kinetic measurement of lime concentration in the bath

The theoretical diffusion coefficient of lime at infinite dilute calculated from equation (12) is value 1.91.10^{-9} m^2 s^{-1} on the base of kinetics measuring in laboratory conditions [10].

3. Optimization of the washing process

The analytic solution of the mathematic model of the bath washing process enabled us to determine the operating costs-function for bath washing of material. It is possible to find the optimum of washing water of process to be a successful course of the process, respectively, and that all from the corresponding operating costs-function [10]. To determine the operating costs-function for the material bath washing we assumed that we are able to eliminate component from the material by the water and that the main operating costs N_C of considered process are given by the sum of the consumed electric energy to the drive of machinery costs N_E and the consumed washing water costs $N_{V.}$

$$N_C = N_V + N_E \tag{13}$$

where the consumed electric energy costs are given by the product of the electric power unit price K_E, the time t and the electromotor input P to the drive of machinery [12].

$$N_E = K_E \cdot P \cdot t \tag{14}$$

Costs of the washing water requirements N_V are given by the product of the unit price of washing water K_V and the washing water volume V_0

$$N_V = K_V \cdot V_0 \qquad (15)$$

The main operating costs N_C :

$$N_C = K_V \cdot Na \cdot V + \frac{K_E \cdot P \cdot F_o \cdot b^2 \cdot (1 + A)}{D} \qquad (16)$$

$$y = \frac{c_0 V_0}{c_p V} = C_0 Na \qquad (17)$$

We supposed as well that the increasing water requirements cause the decreasing of water pollution during the washing whereby the effectiveness of the washing process increases [12]. Thereby the time interval necessary to the drive of machinery is shorter, hence the electric energy costs are decreasing because these are linearly increasing with dependence on time.

This implies that the sum of the water requirements costs and electric energy independence on the water requirements keeps a minimum. If we want to determine the total costs in dependence on the total dimensionless washing water requirements then first it was necessary to determine the dependence of the washing degree *y* (17), which determines the efficiency of the washing process in dependence on the dimensionless time *Fo* and that for the corresponding soak number *Na*.

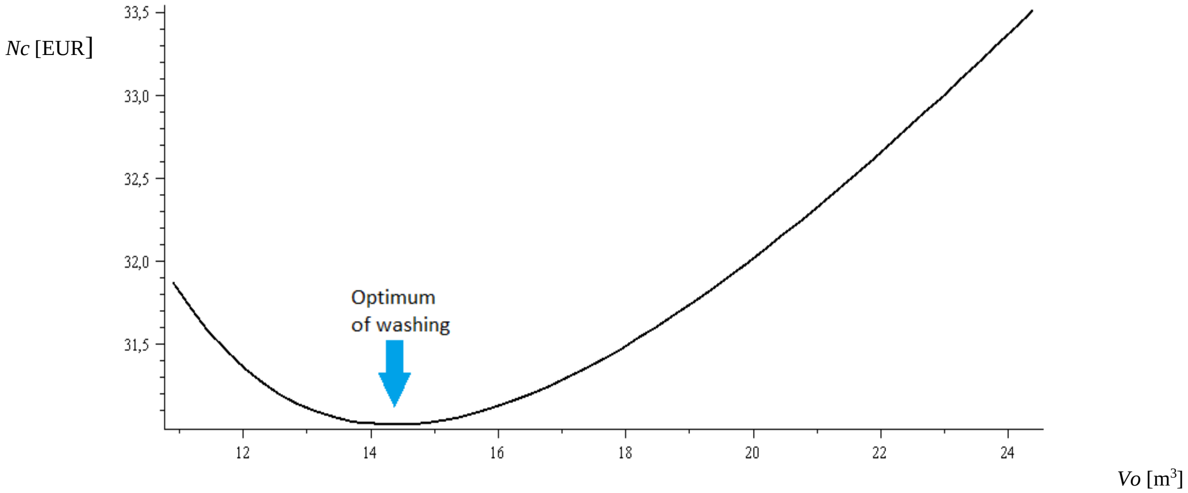

Fig. 4. Cost curve of the washing process

Using values: Volume of washing hide V=1 m^3; Volume of liquid V_0= 5 m^3; Porosity of solid material $\varepsilon = 0.5$,
Initial concentration of bound component in material c_p=0,4kg·m^{-3}; Thickness of solid material $2b=0{,}006$ m;
Effective diffusion coefficient D=1.91.10^{-9} m^2 s^{-1}; Sorption constant $A = 5.11$

5. Limitations and plans

The verification of the proposed diffusion model describing the washing of the partially bound lime component on white skin under laboratory conditions was very difficult for white hide up to a thickness of 5 mm where it was not possible to determine the washed lime interface well. On the other hand, we could clearly identify the required interface for samples greater than 5 mm thick (beef samples). In the next work we plan to determine lime diffusion coefficients for other types of raw hides (bucks rawhide, goat rawhide) and thus can apply the diffusion model proposed by us not only to cowhide.

6. Conclusion

The proposed diffusion model was used to optimize the washed component from hide after deliming. The analytical solution of the mathematical model in the case of washing the one cycle bound component from solid material into an extraction solvent - pure water allowed us to determine the optimal course of scrubbing bound lime on the skin and to determine the minimum process costs from the cost function of the washing process.

Using mathematical modeling of the washing process of bound component, we determined that the cost of water and electricity for washing 1 tonne of raw material was 31 EUR and that water consumption was 14.4. m^3.

For the successful operation of the technological operation, it was necessary to determine the diffusion coefficient of the washed component and its fixing power to the hide on the base of laboratory kinetic measurements. The ecological benefit of the work presented in this paper is to determine the optimum consumption of washing water with respect to the strength of the lime fixing to the white hide. All lime cannot be washed by water as it is only partially soluble and further water washing would be ineffective with minimizing electricity consumption on the process.

7. Acknowledgments

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8. List of using symbols

Symbol	Meaning	Unit
x	position coordinate	m
b	half-thickness of hide	m
ε	porosity of hide	1
Na	soaking number	1
q_n	$n^{\text{-th}}$ root of a certain transcendent equation	1
A	sorption coefficient A	1
B	sorption coefficient B	$m^3 \cdot kg^{-1}$
S	area of hide	m^2
F_o	Fourier number	1
C	dimensionless volume concentration of calcium ions in hide	1
C_0	dimensionless volume concentration of calcium ions in bath	1
X	dimensionless space coordinate	1
K	fixing power	1
K_E	electric power unit price	$EUR \cdot kW^{-1} \cdot h^{-1}$
K_V	the unit price of washing liquid	$EUR \cdot m^{-3}$
N_E	electric energy to the drive of machinery costs	EUR
l_-	anion conductivity	1
l_+	cation conductivity	1
N_V	washing liquid costs	EUR
N_C	the main processes costs	EUR
P	power of electromotor to the drive of machinery	W
Π	electrolyte conductivity	1
T	temperature	K
t	temperature	°C
z_+	valence of cation	1
z_-	valence of anion	1

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