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Modelling of tanning drum as nonadiabatic and non isothermal reactor for dechromation tannery waste

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Abstract: Two different plants for enzymatic hydrolysis were used for presenting enzymatic hydrolysis of chrome shavings. In India an isothermal stirred reactor was employed, in Mexico we used a non- isothermal and non-adiabatic stirred reactor - a tanning drum. An estimate of operating expenses is carried out for Indian conditions, and a calculation was made of charge critical quantity for a tanning drum in conditions of a Mexican tannery. The critical minimal charge of a tanning barrel was estimated on the basis of a model balancing heat transmission from a heated reaction mixture into the environment through reactor walls. The utilisation of tanning barrel for hydrolysis makes possible the processing of tanning wastes in the place of their origin, thus substantially enhancing economics of the whole process

Key-Words Mathematic modelling, enzymatic hydrolysis, tanning process

1 Introduction

The point considered for enzymatic hydrolysis of shavings was application of a non-isothermal and non-adiabatic stirred reactor – a tanning drum. This consideration was based on two fundamental reasons. Firstly, tanning drums are usually to be found directly in the place of origin of tanning wastes and thus make feasible their processing on that very site. Secondly, a small investment into modifying the drum is enough to make it adapted to the required purpose. Both reasons considerably enhance the economics of the whole process. An important step toward analyzing the given procedure was creation of a mathematical model of the mentioned equipment and consecutive simulating calculations.

2 Mathematic Model

In order to try out various possibilities of setting up parameters, preliminary calculations were performed simulating the course of reaction mixture temperature in time dependently on its initial value, and on content of drum.

The temperature of reaction mixture in dependence on time may be calculated by resolving a mathematical model representing the hydrolytic reaction. In an effort at reaching a fast solution we set up a determinist model in accordance with simplified conditions as follow:

- the reaction mixture is intimately stirred by motion of drum
- heat transfer is perfect on both sides of drum wall
- reaction heat of hydrolysis is negligible
- drum has the shape of a cylinder, its radius being at least 10 times greater than thickness of wall so that the temperature field in wall may be described by an "infinite plate" model
- dependence of all physical parameters of the model on temperature is negligible.

Assuming these, we applied the following mathematical model.

$$\frac{\partial t(x,\tau)}{\partial \tau} = a\frac{\partial^2 t}{\partial x^2}(x,\tau);\ 0<x<b;\ \tau>0 \qquad (1)$$

$$m_0 c_0 \frac{\partial t_0(\tau)}{\partial \tau} = S\lambda \frac{\partial t}{\partial x}(0,\tau) \qquad (2)$$

$$t(x,\,0) = t_p \qquad (3)$$

$$t(b,\tau) = t_p \qquad (4)$$

$$t(0,\tau) = t_0 \qquad (5)$$

$$t_0(0) = t_{op} \qquad (6)$$

Equation (1) describes a non-stationary temperature field in the wall of drum. Heat balance expressing equilibrium between rate of decrease in reaction mixture temperature and transfer of heat through reactor wall is described by equation (2). Equations (3) and (4) are initial conditions, and equations (4) and (5) describe conditions of perfect heat transfer. For analytical solution of the given model, Laplace transformation was applied yielding:

$$\frac{t_0-t_p}{t_{op}-t_p}=2\sum_{n=1}^{\infty}\frac{\cos(q_n)\sin\left[(1-X)q_n\right]}{q_n+\sin(q_n)\cos(q_n)}e^{-F_0 q_n^2} \qquad (7)$$

where q_n are roots of the following equation,

$$cotg\,(q) = q.\,Ja \qquad (8)$$

F_o is the Fourier criterion (dimensionless time)

$$F_0=\frac{a\tau}{b^2} \qquad (9)$$

$$X=\frac{x}{b} \qquad (9a)$$

and *Ja* is a dimensionless number expressing the ratio of reaction mixture enthalpy and enthalpy of drum wall.

$$Ja=\frac{m_o c_o \Delta t_o}{m\ \ c\Delta t} \qquad (10)$$

The course of reaction mixture temperature in time thus depends on drum wall thickness *b*, on its coefficient of heat conductivity *a*, mass *m*, specific heat *c*, also reaction mixture mass m_o and its specific heat c_o. The dimensional value of reaction mixture temperature $t_0(\tau)$ is then dependent on its starting temperature t_{op} and on temperature of the environment t_p, which is identical with starting temperature of the tanning drum wall.

The only value to be practically altered among all those mentioned is mass of reactor charge (reaction mixture) m_o and its initial temperature. It is then necessary to choose mass of reaction mixture charge and its starting temperature in such manner that the temperature during required reaction time does not fall below a limit level where reaction rate would be too low.

The non-stationary temperature field in drum wall is shown in Fig. 1 (for *Ja* = 1), and the time course of temperature of the reaction mixture in drum in Fig.2 (equation 7 for $X = 0$).

3 Experimental part

3.1 Description of test

Plant at our disposal comprised a tanning drum of 1.5-m diameter, 1-m width, wall thickness 4.5 cm. We filled the drum with hot water of known mass and starting temperature of 80 oC. An aperture was drilled in the drum wall and an alcohol thermometer fixed/tightly inserted/ therein so that its tip reached sufficiently far into hot liquid.

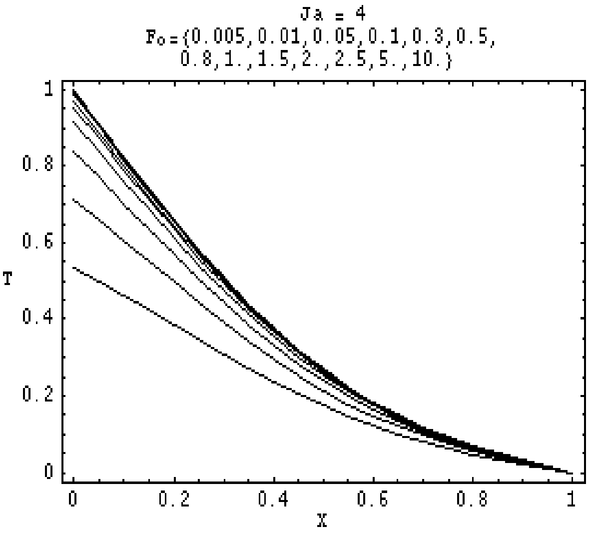

Fig. 1: The non-stationary temperature field in drum wall

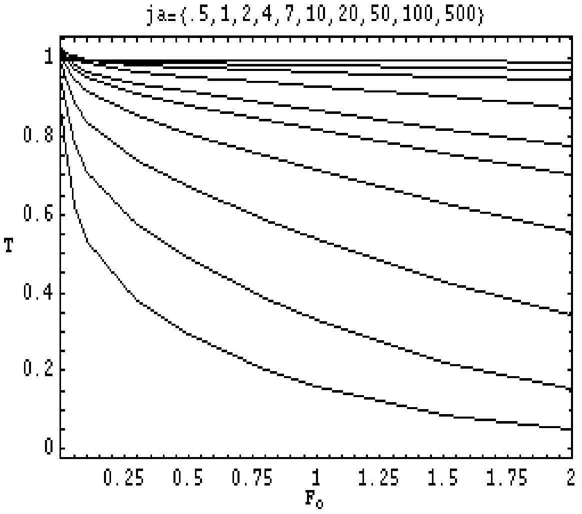

Fig. 2: The non-stationary temperature field in drum wall

Temperature of water inside the rotating drum was measured at regular intervals. As soon as rate of temperature decrease sank/got under 0.05 °C/min, cooled water was let out and drum refilled with hot water of known starting temperature and mass.

3.2 Determining the coefficient of heat conductivity through drum wall

When determining the coefficient of drum heat conductivity, we start from relation (7) and from experimental data of the dependency of water temperature inside the rotating drum on time. In case the time is long enough, members of the infinite series on the right side of equation (7), except for the first, may be neglected, and from the condition thus simplified the value of temperature parameter may be calculated. Considering that the pre-exponential member is independent of time, plotting the logarithm of dimensionless temperature against time produces a straight line from which we may determine the sought-after heat conductivity of drum wall.

$$\frac{t_0 - t_p}{t_0 - t_p} = t^* = K\, e^{-\frac{a\tau}{b^2} q_1^2} \qquad (10)$$

$$\ln t^* = \ln K - \frac{a q_1^2}{b^2}\tau \qquad (11)$$

Following Tab.1 presents experimentally measured temperatures of water in the drum dependently on time. The same is graphically displayed in following Fig.2. Fig.3 serves to determine gradient of linear time dependence of the natural logarithm of dimensionless water temperature in the drum.

Table 1. Test measurements of water temperature inside drum

τ	t_0	T^*	$\ln t^*$
40	52.8	0.589	0.530
50	51.5	0.505	0.571
60	50.4	0.544	0.608
70	49.5	0.528	0.639
80	48.7	0.513	0.668
90	48.1	0.506	0.689
100	47.5	0.491	0.712
110	46.9	0.480	0.735
120	46.5	0.472	0.750
130	45.8	0.459	0.778
140	45.2	0.448	0.803
150	44.8	0.441	0.819
160	44.2	0.430	0.845

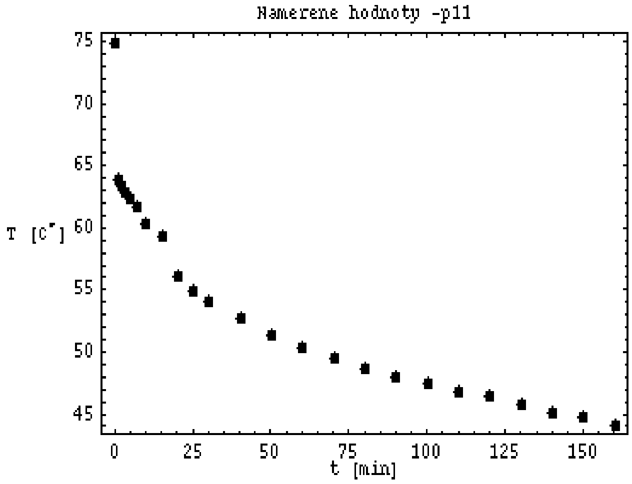

Fig. 3: Experimentally obtained data

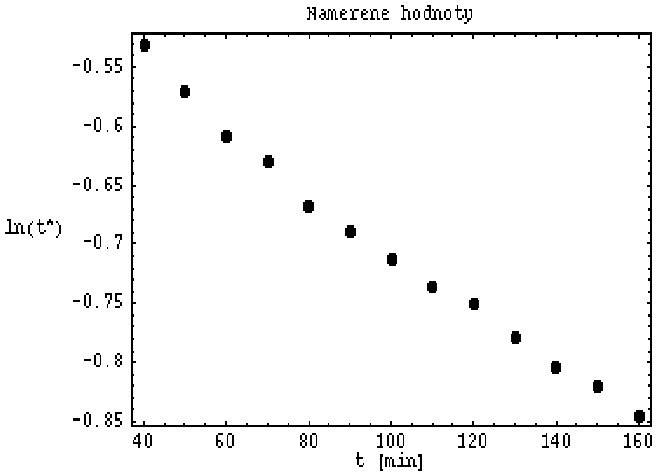

Fig. 4: The line gradient

Applying regression analysis to experimentally obtained data presented in Fig.3 and Tab.I, we determined the line gradient - 0.0026 min^{-1} – Fig. 4.

According to (12), the mentioned value equals $-\frac{a q_1^2}{b^2}$. If we estimate criterion *Ja* equals 0.6 – with a water content of 155 kg in drum – and the corresponding first root of equation (8) q_1 equals 1.02, we may calculate effective heat conductivity $a = 9.5 \times 10^{-8}\, m^2 s^{-1}$. Comparing this value to that of oak wood, $1.3 \times 10^{-7}\, m^2 s^{-1}$, we may claim our calculated value is realistic.

4 Conclusion

The critical minimal charge of a tanning drum was estimated. An estimate was performed of the critical minimal on the basis of a balance model for heat transport from reaction mixture into the environment through reactor wall. Employing a tanning drum for hydrolytic reaction allows to process tanning wastes in the place of their origin, thus considerably enhancing economics of the whole process.

Pilot-plant tests proved the viability of enzymatic hydrolysis in conditions of Indian and Mexican tanneries. Chrome shavings in these countries obviously have a lower fat content, which accelerates hydrolysis . Tests in a preheated drum demonstrated the process of hydrolysis could be realised on this plant, thereby making possible the direct processing of tanned wastes where these immediately originate. Investment costs will also be considerably reduced in this way and thus also the price of hydrolysis products. An approximate estimate of minimal charge for a heated drum can utilise a quasi-stationary model.

List of symbols:

t - temperature of drum wall [^{0}C],
t_0 - temperature of reaction mixture [^{0}C],
t_p - initial temperature of drum wall [^{0}C],
t_{0p} - initial temperature of drum charge [^{0}C],
t_s - drum ambient temperature [^{0}C],
τ - time [s],
a - temperature conductivity coefficient [m^{2} s^{-1}],
x - coordinate of drum wall [m],
b - thickness of drum wall [m],
m_0 - mass of reaction mixture in drum [kg],
c_0 - specific heat of reaction mixture [3 kg^{-1} K^{-1}],
c - specific heat of drum walls [3 kg^{-1} .K^{-1}].
S - total area of drum inner walls (exchange area) [m^{2}],
λ - heat conduct. coefficient of drum walls [W.m^{-1}.K^{-1}],
m - mass of drum walls [kg],

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