Modeling and Microcontroller Control of Raw Hide Soaking in Tannery Industry

P. Doležel, V. Vašek , D. Janáčová, K. Kolomazník, M. Zálešák

***Abstract*—**The paper deals with utilization of Ethernet interface of microcontroller MC9S12NE64 in automatic control of hide soaking process. Microcontrollers are widely used in small or medium size technological processes. Microcontroller is usable for controlling the process described in this paper. The presented algorithm was developed to optimize the soaking process and prevent structural damage of hides that occurs while the hide is sunk and washed in plain water. Such damage is caused by large osmotic pressure that tears the fine structure of the hide. The algorithm was fully implemented into the microcontroller which controls the whole process. The Ethernet interface was used for interconnection with a computer. Web server is also part of the microcontroller so that the whole application is saved in the microcontroller`s flash memory. The computer only requires installation of a common web browser to provide successful communication with the microcontroller.

***Keywords*—**Manufacturing technology, soaking, Tannery industry, system mathematical model, measuring and control microcomputer system, simulation, Ethernet, webserver.

I. Introduction

Embedded systems are widely used for controlling small or medium sized technological processes [Axelson, 2003]. The utilization of microcontrollers has many advantages compared to common computers. Microcontrollers are cheap, small and have many useful functions prepared for direct use in technological processes. In addition there are microcontrollers equipped with built-in Ethernet interface that provides communication. Ethernet offers better options in data transfer compared to common serial communication (RS232, RS485, USB,…) used so far.

The goal of this paper is to show one of the possible applications of the microcontroller's Ethernet interface for controlling technological process of raw hide soaking.

Soaking processes because many technological processes are characterized by large consumption of water, electrical energy and auxiliary chemicals mainly. For this reason it is very important to deal with them. For the optimization of process of washing it is possible to set up an access of the indirect modeling that is based on make-up of mathematical models coming out of study of the physical operation mechanism. The process is diffusion character it is characterized by the value of diffusion effective coefficient and so called structure power of the removing item to the solid phase. The mentioned parameters belong to input data that are appropriate for the automatic control of soaking.

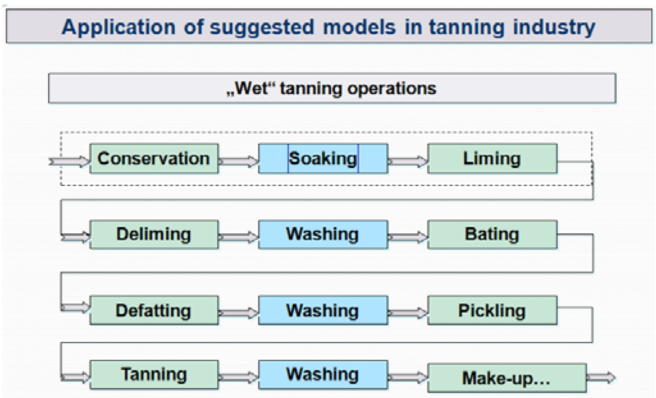

Fig.1: Tanning processes [D. Janáčová, et al, 1997]

Raw hides have to be conserved before they are used in tanning industry. There are several ways of conservation. It might be done by solid crystal salt, in salt solution or by pickling (salt solution with sulfur acid). Hides are delivered to tanneries in dry condition. There are many wet operations that change such dry hides to flexible and usable intermediate product. The soaking and desalting are included in these operations. The goal of this process among others is salt removal from the hide.

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Raw hide conservation:

- Raw hide subject of fast enzymatic digestion
- Conservation is needed before they are used
  - Dry salting – by crystalic sodium chlorid
    - 0,5-1kg NaCl per 1kg hide, ~3 weeks
  - Salt solution – sodium chlorid solution
    - ~48 hours of soaking

Preparing for tannery treatment:

- Soaking – clean and water transport to hide material
  - Removal of non-fibre hide proteins
  - Splitting the fibre structure
- Stage washing, Multi stage washing, Contiunal washing

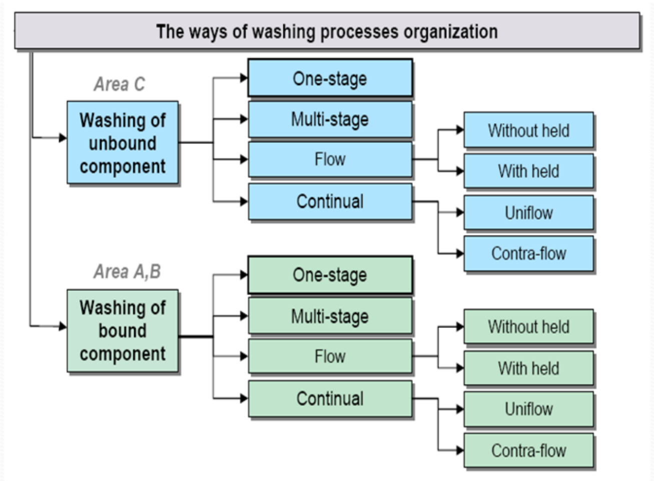


Fig. 2 The cases of washing processes adjustment[D. Janáčová, et al, 2007]

This process is usually done in large drums where hides are washed in plain water. There are several ways of washing [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.

2) Decantation washing, where hide is washed with plain water in several steps. In this case it is always necessary to wait until the salt concentrations in the hide and washing bath equalize.

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.

Raw hide tanning, soaking and desalting belong to 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].

Usually the hide is sunk into plain water. In such system the salt concentration rapidly decreases on the hide surface and then rises again. This rapid fall of concentration can be seen in Figures 3 and 4 are causes large osmotic pressure that can damage the fine surface structure of the hide [Kolomaznik et al., 2006].

This is more obvious in soft hides such as goatskin or sheepskin.

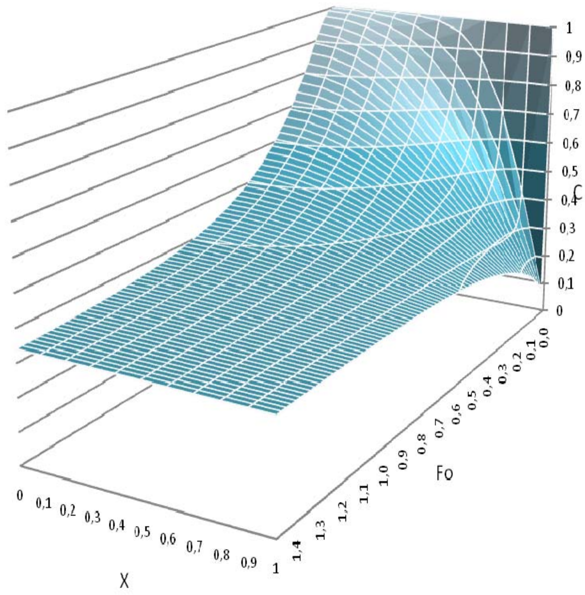


Fig. 3 Concentration shock on the surface

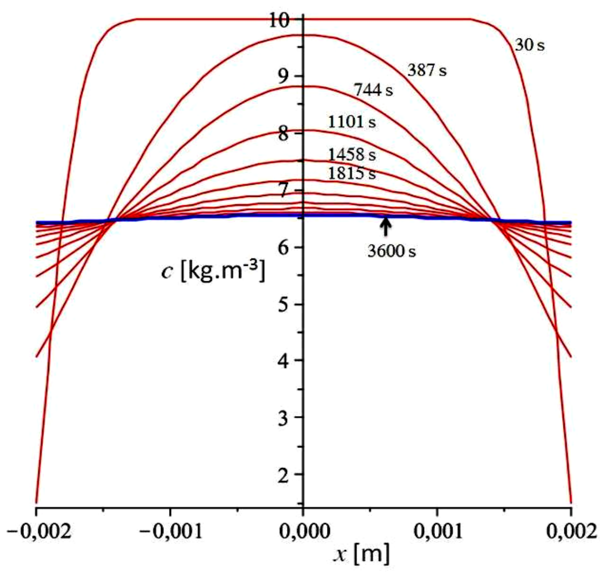


Fig. 4 Concentration field in the raw hide for the specific operation time [D. Janáčová, et al, 2007]

This effect might be eliminated by sinking the hide into the salt solution. In this case there is no longer such rapid concentration fall and only small osmotic pressure. The control algorithm described in this paper eliminates large osmotic pressure and reduces the concentration differences between the hide surface and its inner structure.

The algorithm was implemented in a microcontroller with an Ethernet interface. The Ethernet was used to connect the microcontroller to a PC and to obtain data from the microcontroller and display them in graphical environment on the computer screen.

II. THEORY –MATHEMATICAL MODEL

The control of soaking process is based on a mathematical model. The system of desalting is shown in Figure 5.

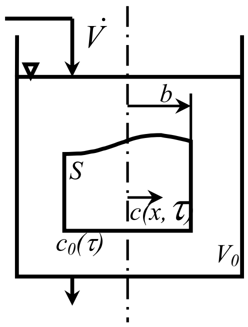


Fig. 5 Model of the flow system

where:

- τ – time
- b – maximal sample thickness
- x – variable sample thickness
- S – sample surface area
- c – salt concentration in sample
- c_0– salt concentration on the sample surface
- V_0 – bath volume
- $\dot{V}$ – flow rate

Raw hide is sunk into the solution with specific salt concentration and then the plain water is driven into this system while the waste water is flowing out.

The system is described by Fick's second law of diffusion [Kolomaznik et al., 2006]:

$$\frac{D\partial^2 c(b,\tau)}{\partial x^2} = \frac{\partial c(b,\tau)}{\partial \tau} \tag{1}$$

$$c_0(0) = c_{0p} \tag{2}$$

$$\frac{\partial c}{\partial x}(0,\tau) = 0 \tag{3}$$

$$c(x,0) = c_p = \varepsilon \cdot c_{0p} \tag{4}$$

$$-\frac{DS\partial c(x,\tau)}{\partial x} = \frac{V_0 \partial c_0(\tau)}{\partial \tau} + \dot{V} \cdot c_0(\tau) \tag{5}$$

Condition (2) shows the initial distribution of soaking component concentration in solid phase-material. Condition (3) denotes that field of concentration in solid material is symmetric. Equation (4) holds under condition of a perfectly mixed liquid phase. Boundary balance condition (5) 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.

By introducing dimensionless variables we got:

$$-\frac{\partial C(X,F_0)}{\partial X} = L\left[C_0(F_0)+1\right] + \frac{N_a}{\varepsilon}\frac{\partial C_0(F_0)}{\partial F_0} \tag{6}$$

where the dimensionless quantities have the form:

$$X = \frac{x}{b} \qquad F_0 = \frac{D \cdot \tau}{b^2} \qquad N_a = \frac{V_0}{S \cdot b} \qquad L = \frac{\dot{V} \cdot b}{S \cdot D \cdot \varepsilon} \tag{7a,b,c}$$

$$C = \frac{c - \varepsilon \cdot c_{0p}}{c_p} \qquad C_0 = \frac{\varepsilon\left(c_0 - c_{0p}\right)}{c_p} \qquad L = \frac{\dot{V} \cdot b}{S \cdot D \cdot \varepsilon} \tag{7d,e,f}$$

The initial concentration value is $C(X,0) = 0$. By means of Laplace transformation we obtained analytic solution. Final solution given by dimensionless concentration .The solution for the through-flow systems is :

$$C(X,F_0) = -1 + 2L \cdot$$
$$\cdot \sum_{n=1}^{\infty} \frac{\cos(X \cdot q_n) e^{\left(-F_0 \cdot q_n^2\right)}}{q_n \sin(q_n) + q_n^2 \cos(q_n) + q_n L \sin(q_n) + \frac{2N_a q_n^2 \cos(q_n)}{\varepsilon} - \frac{q_n^3 N_a \sin(q_n)}{\varepsilon}} \tag{8}$$

The roots q can be calculated from the transcendent equation:

$$tg(q) = \frac{L}{q} - \frac{N_a}{\varepsilon} q \tag{9}$$

On the figures 6, 7 can be seen the concentration course for constant water flow. There is no concentration show at the beginning of the process; however, the concentration difference between surface and center of the hide is large and the whole process is inefficiently long.

The control algorithm described in this paper was developed according to mathematical model described above. The goal of this algorithm is to eliminate the concentration shock and change the salt concentration decrease from exponential to a linear character. (II.1)

The linear behavior shortens the whole time needed for desalting process and eliminated large differences in concentration inside the hide. (II.2) The process ensures maximal care for the quality of the hides. The hide does not suffer from the osmotic pressure that damage its fine structure.

The hide preserves the quality which saves expenses. This effect is more obvious with the fine hides such is goatskin, calfskin or sheepskin.

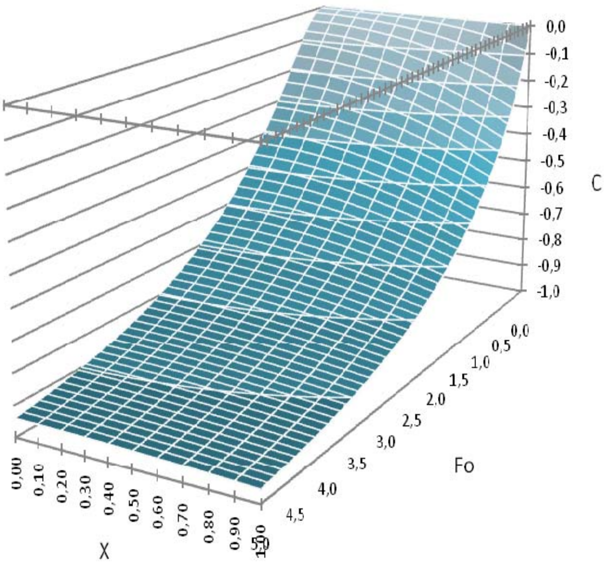


Fig. 6 Concentration course for constant water flow L=2

These skins suffers from concentration shock more dramatically than for example cow hide.

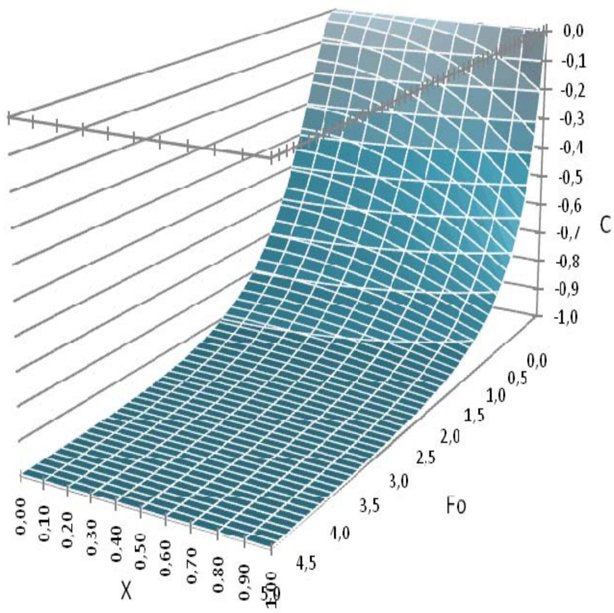


Fig. 7 Concentration course for constant water flow L=5

OPTIMIZATION OF SOAKING PROCESS

We supposed as well that the increasing washing liquid requirements cause the deCreasing of washing liquid pollution during the washing whereby the effectiveness of washing process increases. 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 washing liquid requirements costs and the electric energy in dependence on the washing liquid requirements keeps a minimum.

If we want to determine the total costs in dependence on the total dimensionless washing liquid requirements then first it is necessary to determine the dependence of the washing degree y, which determines the efficiency of the washing process in dependence on the dimensionless time Fo and that for the corresponding soak number Na. Dependence of the washing degree y, on the dimensionless time Fo is given by equation (14) [8].

$$y = \frac{\dot{V}}{c_p V + c_{0p}\varepsilon V_0} \int_0^\tau c_0 \cdot d\tau \qquad (14)$$

$$\int_0^\tau c \cdot d\tau = 2Lc_p \sum \frac{1}{L + L^2 + q^2\left(\frac{N_a}{\varepsilon} - 2L\frac{N_a}{\varepsilon} + 1\right) + q^4\left(\frac{N_a}{\varepsilon}\right)^2} \cdot \frac{b^2}{q^2 D} \cdot \left(1 - e^{-\frac{q^2 D\tau}{b^2}}\right) \qquad (15)$$

In the Fig. 8 is depicted dependence of the washing degree on the time.

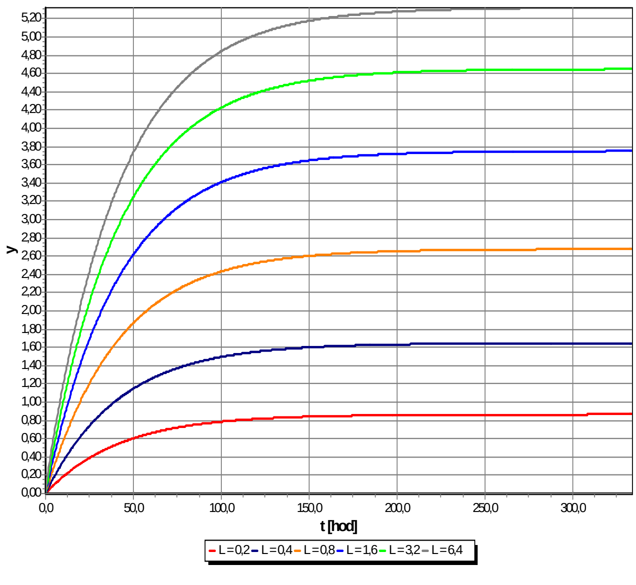


Fig. 8 Dependence of soaking degree on the time for variable L

This paper brings effective approach that ensures optimal desalting process. The linear behavior of the concentration course is achieved by implementation of the following algorithm:

$$u_k = \frac{w \cdot u_{k-1}}{y_k} \cdot K \quad (16)$$

where $K = 8.75 \cdot w^2 - 5.5 \cdot w + 0.0625$ (17)

The u in the equation is the controlled value (flow rate of plain water), w is a set point (required gradient of the concentration degression) and y is the measured value (conductivity which is proportional to the salt concentration in the solution). The constant K is used for delay elimination and usually varies between values from 1 to 1.6.

The application of the algorithm is shown on figure 9. As can be seen the differences of concentration inside the hide are low thanks the linear behavior of the decreasing salt concentration in place of exponential.

The desalting process depends on measuring of concentration, plain water flow or controlling the basic peripheries (valves, motors or pumps). The A/D converter, inputs and outputs are essential parts of any microcontroller.

That's why microcontroller was used for controlling this process.
However, it is useful to visualize the process on the screen in an interactive way.

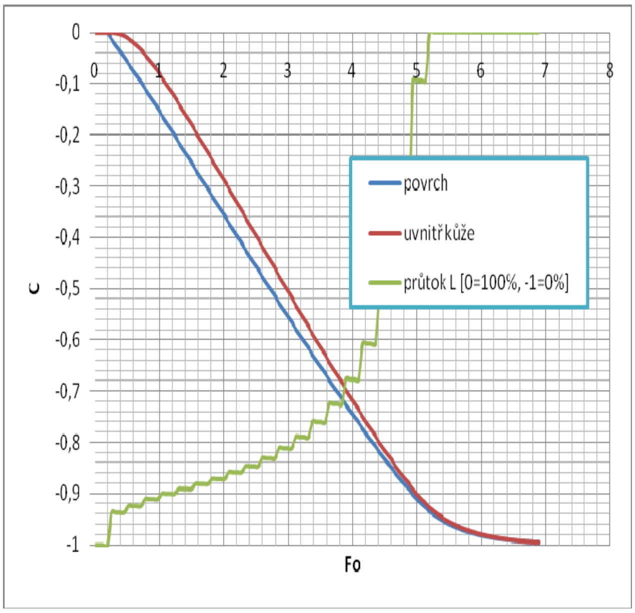


Fig. 9 Controlled desalting process - simulation

This can be done by an additional application that runs on the computer and communicates with the microcontroller. This application has only interactive function and does not contain any control algorithm.

There are several options to accomplish the interconnection. It might be done by serial communication such is RS232 or RS485, by CAN interface or by Ethernet. Today, the majority of commercially available equipment is based on the RS-232-C and RS-232-D standard [Eady, 2004]. However, there are already lots of embedded systems with this interface.

It is easy to use and usually does not require any special device. In this work Ethernet was chosen because of its widespread utilization.

An embedded system that supports Ethernet requires Ethernet controller hardware to provide the Ethernet interface. Many Ethernet controller chips are designed for use in desktop computers and include support for standard PC buses and Plug-and-Play functions. Small embedded systems typically don't need all of the capabilities of a PC's Ethernet controller. A few of the older, simpler PC controllers have found new life in embedded systems. [Axelson, 2003]

The Ethernet interface is a part of OSI (Open Systems Interconnection) standard. This standard is divided into several layers: physical, data link, network, transport, session, presentation and application layer. Each layer has its own function. The Ethernet represents the data link layer. The network layer is usually represented by IP protocol and the transport layer is usually represented by TCP or UDP protocol. The session, presentation and application layers might be joined into a single layer that is represented by any application.
Many embedded systems use IP with TCP or UDP, but for some applications, the Ethernet driver can communicate directly with the application layer [Axelson, 2003].

III. Implementation

The algorithm was verified also on an experimental device created by modification of an old washing machine. This machine was equipped with two flow meters, a valve and secondary water circulation for a conductivity sensor. The whole device is controlled by a control unit.

A. Control unit

The Freescale microcontroller MC9S12NE64 is a part of the control unit that contains a mainboard and an Ethernet core unit (Figure 10). The Ethernet core unit is inserted into two slots located on the mainboard.

The minimum requirement for the CPU is a microcontroller with an external 8-bit data bus. In case of MC9S12NE64 it is provided by Ethernet Physical Transceiver Module (EPHY) and Ethernet Media access controller (EMAC). The 8K system RAM functions as the Ethernet buffer while the EMAC module is enabled. It will occupy 0.375K to 4.5K of RAM. The Ethernet buffer operation of the RAM is independent of the CPU and allows same cycle read/write access from the CPU and the EMAC. No hardware blocking mechanism is implemented to prevent the CPU from accessing the Ethernet RAM space, so care must be taken to ensure that the CPU does not corrupt the RAM Ethernet contents. [Freescale, 2006]

The mainboard is powered by a power module that transforms the input voltage of 24V into 12V, 5V and 3.3V. The conductivity sensor is powered by 24V, flow meters by 12V and the microcontroller itself is powered by 3.3V. The 5V is used for the controlling action elements (motor, pumps, valve etc.).

The output signal of the conductivity sensor is between 4 to 20 mA. This is transformed to 0-5V and read by an AD converter of the microcontroller.

The flow meters have impulse output that is processed by interrupts of the H port of the microcontroller. The impulse counter also provides information about direct water consumption.

The control unit contains several reserved I/O which are not used for this application. These reserved ports might be used for another purpose. These features make the control unit more universal and suitable for multifunctional utilization. All used ports are listed in the Table 1.

The microcontroller and its Ethernet core unit were delivered with OpenTCP library. This library was developed by Viola Systems and is written completely in C language and might be used with different microcontrollers and not only Freescale.

The MC9S12NE64 contains also a simple web server. Files with web pages and applications are saved on a 1 MB flash memory. The server has a few limitations.

Any web page on the server may contain only three external objects (CSS file, image, javascript etc.). This is the number of simultaneously served requests which the microcontroller is capable to process. This is the reason why the serving application is limited to java applet or flash animation; however, the total number might be changed in the configuration file.

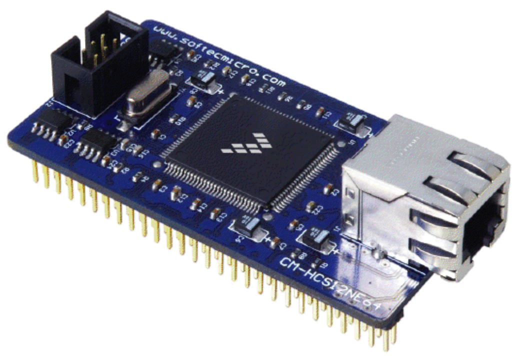


Fig. 10 Ethernet module with microcontroller

Port	Range	Usage
A B	0-7 0-7	I/O pins used for controlling actuators such is motor, pump or valve
G	0-7	This port is used for buttons situated on control unit
H	0-6	This port is used as a counter for flow meter
S	0-1	Used for serial communication (exclusively for programming and debugging purpose)
T	4-7	Reserved I/O
PAD	0-3	AD converter for conductivity sensor

Table 1 Ports used in control unit

The box of the control unit contains several inputs and outputs. They are described in Table 2.

Abbr	I/O	Function
C	I	Conductivity sensor
P1	I	Input flow meter
P2	I	Output flow meter
V	O	Input valve of pure water
R	O	On/Off drum rotor
M1	O	Secondary circuit pump
M2	O	Pump at the output of bath solution
Eth	I/O	Ethernet
RS232	I/O	Serial port

Table 2 Inputs and Outputs of the control unit

B. Application description

In this paper, flash animation (Figure 11) was used for its easy visual implementation of the whole process. The communication between the microcontroller and computer is similar with the same communication in java applet.

The communication process is based on requests that are run periodically in a specific time span. When the flash application is loaded in the web browser, the request of the current system state is sent. The result contains all information about the control process state (concentration, water consumption, time of process control etc.). After this initial step only the basic state is requested repeatedly because the state might be changed directly on the control unit by pushing the buttons. The action elements might be switched on or off also from the application by clicking on interactive elements in the flash animation.

Flash application doesn't control the desalting process. It only visualizes the process by reading the actual state of the experimental model. The response has to be fast enough for providing current state of the system in realtime.

The valve (Fig. 12a) control the input of the water flow. Clicking on this element the valve might be switch on or off. The flow is constant and equal to 24,6 $l.min^{-1}$.

The water flow at the output is controlled by pump. The pump is represented in the falsh animation by motor which can be switched on or off by clicking on the element (Fig. 12b). The water flow is also constant and equal to 9,29 $l.min^{-1}$. This flow is also the maximal flow of the systém that provides constant volume of the bath.

The flow is calculated by the algorith during the process; however, the constant flow might be set directly in the flash application. Because the on/off control of the flow at the input and output the constant flow has to be controlled by PWM (Figure 13).

The flow is set according to specific time span. For the experimental device the time span was equal to 20 seconds.

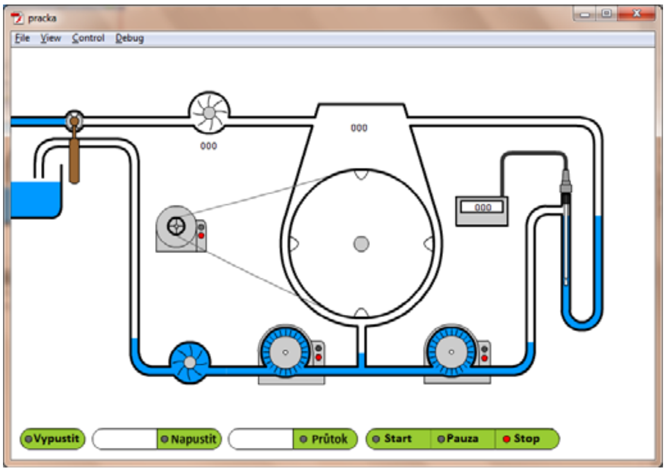
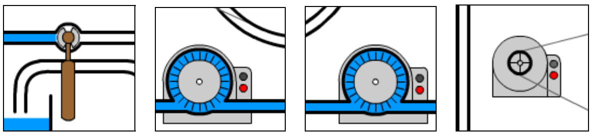


Fig. 11 Flash visualization



a b c d

Fig. 12 Action elements of the flash animation

The flow is set according to specific time span. For the experimental device the time span was equal to 20 seconds.

The secondary circulation circuit is controlled by the second pump represented by the element that is shown on the Figure 12c. The conductivity sensor is placed in this circuit and measure the conductivity of the bath. The water flows constantly during the soaking process through this circuit. The actual conductivity is shown on the right side of the drum (Figure 11). The conductivity is also displayed on the display situated on the case of the conductivity sensor.

The secondary circulation circuit is controlled by the second pump represented by the element that is shown on the Figure 8c. The conductivity sensor is placed in this circuit and measure the conductivity of the bath. The water flows constantly during the soaking process through this circuit. The actual conductivity is shown on the right side of the drum (Figure 14). The conductivity is also displayed on the display situated on the case of the conductivity sensor.

The salt concentration has to be equaly distributed in the bath solution. This is done by the drum rotor. It is controlled by the element shown on Figure 8d.

The water consumption is shown on the water counter just behind the input valve and the actual bath volume is shown at the top of the drum (Figrue 14).

Application communicates with control unit via the TCP/IP socket based interface. Whole application is saved in web server directly in control unit.

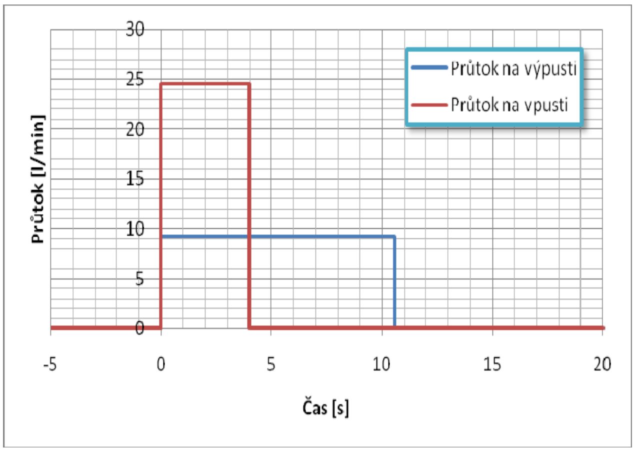


Fig. 13 The water flow PWM control

Connecting computer via Ethernet wire and setting up the IP address of the control unit, the website with the application is loaded. The only additional application which is needed is the Flash browser plugin. Every think else is saved in control unit.

C. Results

Figure 14 shows measurements of constant plain water flow for different flow rates. As can be seen the hide is sunk into a solution with specific salt concentration and no concentration shock occurs. The concentration decreases in exponential manner. It resulted in high differences between salt concentration inside the hide and on its surface.

Changing the characteristic into linear behavior the differences between concentrations inside the hide and on the surface are much smaller. In Figure 15 is shown the controlled system. The flow rate is controlled by the algorithm described above.

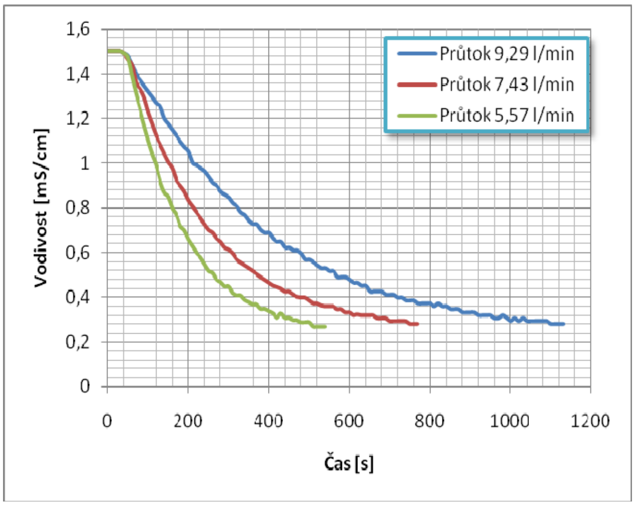


Fig.14 Conductivity course for different volume flow

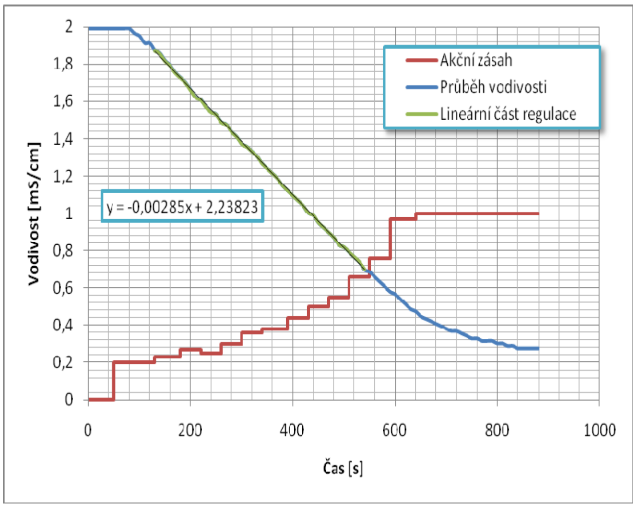


Fig.15 Controlled flow rate

The data is repeatedly sent into the computer through the Ethernet for obtaining these characteristics.

IV. CONCLUSION

The results show that linear behavior is achieved successfully by implementing the algorithm. The concentration linear course and starting soaking process in salt solution eliminates the concentration shock that is the cause of the osmotic pressure. The pressure irreversibly damage the fine structure of the hide. The thin and fine skins (goatskins, sheepskins, calfskins,…) that are usually more expensive than thick skins (cow skin) are very inclinable to the osmotic pressure. Application of this approach in the soaking and desalting process can save high expenses connected with expensive skins and their quality.

It is also shown that utilization of a microcontroller is high enough for this purpose and the Ethernet interface is useful for connecting to supperior system for visualization of such processes. It is easy to use as well as widespread and accesible in almost all computers or portable devices. The web server containing the visualization flash application ensures interportability. While communication based on USB, RS323 or CAN interface needs aditional software installation before it might be used, the Ethernet interface with web server and flash application (or java applet) ensures instantaneous use. The only required application is a common web browser that is a basic part of any operationg system.

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