Proceedings of the 6th WSEAS International Conference on Applied Informatics and Communications, Elounda, Greece, August 18-20, 2006 (pp349-352)

Control algorithms in a minimum of main processing costs for production amaranth hydrolyzates

KAREL KOLOMAZNIK, DAGMAR JANACOVA, VLADIMIR VASEK, MICHAELA UHLIROVA
Tomas Bata University
Faculty of Applied Informatics
Mostni5139, 760 01 Zlin
CZECH REPUBLIC

Abstract: - Treatment of amaranth produces valuable commodities heaving great meanings for human health and live. Mainly amaranth hydrolyzates both producing low molecular sugars and peptides. There is a need to optimize process of hydrolyze and separation of final products. Using theoretical tools of processing engineering the control algorithms in a minimum of main processing costs for production amaranth hydrolyzates was established.

Key-Words: - Process Engineering, Control Algorithms, Amaranth Hydrolyze

1. Introduction

Amaranth is characteristic for exceptionally high protein content and a very good assimilation property. Compared with other existing cereals, amaranth has a higher proportion of the amino acid lysine, which is important for mental development, and also a significant proportion of high-quality vegetable oils. Amaranth guarantees a well-balanced diet as for mineral substances, namely calcium, magnesium, iron and vitamins B, C and E. This all makes amaranth a potential food resource for the third millennium.

The existing procedures of food processing enable us to separate or concentrate some amaranth components and thus to obtain products that are intentionally more effective. These substances are then used as food supplements for particular nutritional uses. For example amaranth oil in the USA is in the category of clinically tested medical products. The amaranth pulp concentrate is a high-quality food supplement compared with other pulps for a high content of natural minerals and being gluten-free.

Amaranth is a good food supplement not only for a healthy population, but it can be used also for some patients as a diet, medicine or prophylaxis. Further, amaranth is proved suitable in the following areas:

- for nurslings as a part of paps and ablactation diet, because amaranth is gluten-free
- for children for its high content of lysine and histidine that are essential for a normal mental development and for growth
- as a food supplement for sportsmen for its high content of vitamins and a high-quality protein
- for population suffering from persistent stress (positive effect of the protein, minerals and fat composition)
- as a prophylaxis and treatment of constipation and its complications for a high content of pulp and starch of a high water-binding property
- For prophylaxis and treatment of fat metabolism disorders, increased level of cholesterol and resulting complications (arteriosclerosis, apoplexy, ischemic heart disease, heart attack, angina pectoris) – positive effect of amaranth pulp and unsaturated fatty acids
- as a supplement for reduction diet of obese patients for a high content of carbohydrates and pulp together with the high-quality protein and proper fat composition
- as a part of gluten-free diet for patients suffering from Celiac Disease (amaranth is a naturally gluten-free nutrition with a high content of protein)
- amaranth is suitable for patients with food allergy for low antigen potential of its protein
- for diabetes patients (amaranth contents compound, slowly degradable carbohydrates)
- for people with alternative ways of nutrition (vegetarians, macrobiotics) as a high-quality source of protein
- for food flavouring (specific nut flavour)
- preparation of müsli mixtures – heat treated grains – “pop”
- production of bakery stuff with addition of amaranth flour. (By mixing of amaranth flour with another kind of flour we get a unique nutrition value. Its protein and amino acid composition approaches the ideal model

specified in 1973 by the Food and Agriculture Organization and the World Health Organisation FAO/WHO of the OSN)

- production of confectionary with addition of amaranth flour or “pop”

From the above mentioned list there is obvious that amaranth can be widely used in foodstuff industry and its utilization in this field is dominant. The foodstuff industry processes not only amaranth grain, but also leaves and haulm.

For its unique composition, amaranth also has a wide application in medicine. In the Czech Republic, amaranth is examined from the medical point of view in the Faculty Hospital in Hradec Králové (Clinic of Gerontology and Metabolism). The research carried out there has an international character. From pharmacological point of view, sqalene from amaranth is tested as a possible cancer treatment.

Amaranth has also been successfully used in cosmetic industry as an additive in natural herbal cosmetics, especially amaranth oil, which has a very positive effect on sensitive skin. The oil contents active substances that make a natural component of skin film and thus do not disturb its protective function, it penetrates deeper into the skin than other oils, the skin remaining smooth and pliant. For the above mentioned properties, the amaranth oil is also suitable as a component of children’s cosmetics. Amaranth starch is another amaranth component used in cosmetic industry, especially for a very small size of starch grains.

The industrially most important part of amaranth flower is its grains, in some cases the leaves. Only very few publications deal with a complex utilization of amaranth mass, i.e. the remnants after the leaves and grains removal.

In the Czech Republic there are two main companies that are engaged in amaranth research – AMR AMARANTH a.s. and Ateko a.s. The results of their research have been already put into practice in many of the above mentioned areas.

Further research is carried out, e.g. in the area of processing the amaranth biomass. In 2003, the goals of the project of the complex utilization of amaranth biomass were achieved – application of extracts and modified biomass in other fields of research, the possibility of utilization of amaranth biomass in an early stage of growth as a source of nutritionally interesting substance, tests of anaerobic fermentation of the amaranth biomass with the use of a model laboratory apparatus. This way has not been comprehensively elaborated so far, as well as the question of production of the amaranth valuable components has not been solved from the point of view of process engineering.

The objective of this contribution is to study the amaranth mass fermentation, to quantify it and to elaborate a simple kinetic model that would suitably describe the whole process.

2. Theory

The microbial anaerobic decomposition is a set of partial biological processes following one after another. The decomposition of organic compounds to the final products – methane and carbon dioxide – requires a coordinated metabolic co-operation of the participating bacteria species. The product of one group of micro organisms makes the substrate for another group, i.e. an insufficient activity of one group can disturb the dynamic equilibrium of the whole system and thus to decrease the process efficiency. The main processes of anaerobic decomposition are as follow:

- Hydrolysis
- Acidogenesis
- Acetogenesis
- Methanogenesis

3. Results and discussion

Modeling of the fermentation process

The mathematical simulation of the amaranth anaerobic decomposition consists of the following expected steps:

- Degradation
- Hydrolysis
- Acetolysis
- Methanogenesis

We can describe the process through the following scheme:

$$A \xrightarrow[k_1]{\text{degradation}} B \xrightarrow[k_2]{\text{hydrolysis}} C \xrightarrow[k_3]{\text{acetolysis}} D \xrightarrow[k_4]{\text{methanogenesis}} E$$

where k_1 - k_4 are the speed constants of the individual follow-up reactions.

Assuming that all the reactions will are of the first order, we get the following system of differential equations:

$$\frac{dc_A}{d\tau} = -k_1 c_A \qquad (1)$$

$$\frac{dc_B}{d\tau} = k_1 c_A - k_2 c_B \qquad (2)$$

$$\frac{dc_c}{d\tau} = k_2 c_B - k_3 c_c \qquad (3)$$

$$\frac{dc_D}{d\tau} = k_3 c_C - k_4 c_D \qquad (4)$$

$$\frac{dc_E}{d\tau} = k_4 c_E \qquad (5)$$

The differential equations (1)-(5) we can express as a matrix equation.

$$\begin{bmatrix} \dot{c}_A \\ \dot{c}_B \\ \dot{c}_C \\ \dot{c}_D \\ \dot{c}_E \end{bmatrix} = \begin{bmatrix} k_1 & 0 & 0 & 0 & 0 \\ k_1 & -k_2 & 0 & 0 & 0 \\ 0 & k_2 & -k_3 & 0 & 0 \\ 0 & 0 & k_3 & -k_4 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix} \cdot \begin{bmatrix} c_A \\ c_B \\ c_C \\ c_D \\ c_E \end{bmatrix} \qquad (6)$$

$$\dot{C} = A \quad . \quad C \qquad (7)$$

Equation (7) is a vector differential equation with the following initial conditions:

$$\begin{bmatrix} c_A(0) \\ c_B(0) \\ c_C(0) \\ c_D(0) \\ c_E(0) \end{bmatrix} = \begin{bmatrix} c_{A0} \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} = C(0) = C_0 \qquad (8)$$

The vector differential equation (7) with the boundary condition (8) expresses a linear model. For this reason, it can be solved with the use of Laplace transformation. As the Laplace image of the vector $C(\tau)$ we use

$$c_L = \int_0^\infty c_{(\tau)} \cdot e^{-s\tau} \qquad (9)$$

Applying the Laplace transformation on the equation (7), we get:

$$sC_L - C_0 = A \cdot C_L \qquad (10)$$

Then for C_L:

$$C_L = \left(sI - A\right)^{-1} \cdot C_0 \qquad (11)$$

Where *I* is a unit matrix, so for (*sI-A*):

$$\left(sI - A\right) = \begin{bmatrix} s+k_1 & 0 & 0 & 0 & 0 \\ -k_1 & s+k_2 & 0 & 0 & 0 \\ 0 & -k_L & s+k_3 & 0 & 0 \\ 0 & 0 & -k_3 & s+k_4 & 0 \\ 0 & 0 & 0 & -k_4 & s \end{bmatrix} \qquad (12)$$

The matrix (12) is an upper triangle matrix. In this case, a simplified algorithm for calculation of the elements of its inversion matrix can be used in the way that the final result for the Laplace image of the vector differential equation can be expressed like this:

$$C_L = \left(sI - A\right)^{-1} C_0 = \begin{bmatrix} \dfrac{c_{A0}}{s+k_1} \\ \dfrac{k_1 c_{A0}}{\left(s+k_1\right)\left(s+k_2\right)} \\ \dfrac{k_2 k_1 c_{A0} \quad =}{\left(s+k_3\right)\left(s+k_2\right)\left(s+k_1\right)} \\ \dfrac{k_3 k_2 k_1 c_{A0}}{\left(s+k_4\right)\left(s+k_3\right)\left(s+k_2\right)\left(s+k_1\right)} \\ \dfrac{k_4 k_3 k_2 k_1 c_{A0}}{\left(s+k_4\right)\left(s+k_3\right)\left(s+k_2\right)\left(s+k_1\right)} \end{bmatrix} A \qquad (13)$$

To determine the elements of the original matrix C, we use the reverse Laplace transformation with the use of Heaviside’s theorem:

$$L^{-1}\left\{\frac{f_{(s)}}{F_{(s)}}\right\} = \lim_{s \to s_n} \sum_{i=1}^{n} \frac{e^{s_n \tau}\left(s - s_n\right)}{F_{(s)}} \qquad (14)$$

Where sn are the roots of the equation F(s) = 0. With the use of (14) we then obtain the time profiles for the individual concentrations of the starting substance, products and intermediate products:

$$c_A = c_{A0} e^{-k\tau} \tag{15}$$

$$c_B = \frac{c_{A0} k_1}{k_1 - k_2}\left(e^{k_L\tau} - e^{-k_1\tau}\right) \tag{16}$$

$$c_C = c_{A0} k_1 k_2 \left[\begin{array}{l} \dfrac{e^{-k_1\tau}}{(k_3-k_1)(k_2-k_1)} + \\ + \dfrac{e^{-k_2\tau}}{(k_3-k_2)(k_1-k_2)} + \\ + \dfrac{e^{-k_3\tau}}{(k_2-k_3)(k_1-k_3)} \end{array}\right] \tag{17}$$

$$\begin{gathered} c_D = k_3 k_2 k_1 c_{A0} \left[\begin{array}{l} \dfrac{e^{-k_4\tau}}{(k_2-k_4)(k_1-k_4)(k_3-k_4)} + \\ + \dfrac{e^{-k_2\tau}}{(k_4-k_2)(k_3-k_2)(k_1-k_2)} \end{array}\right] + \\ + \left[\begin{array}{l} \dfrac{e^{-k_3\tau}}{(k_4-k_3)(k_2-k_3)(k_1-k_3)} + \\ + \dfrac{e^{-k_1\tau}}{(k_4-k_1)(k_3-k_1)(k_2-k_1)} \end{array}\right] \end{gathered} \tag{18}$$

$$\begin{gathered} c_E = 1 + k_4 k_3 k_2 k_1 c_{A0} \times \\ \times \left[\begin{array}{l} \dfrac{e^{-k_4\tau}}{-k_4(k_3-k_4)(k_2-k_4)(k_1-k_4)} + \\ + \dfrac{e^{-k_3\tau}}{-k_3(k_4-k_3)(k_2-k_3)(k_1-k_3)} \end{array}\right] + \\ + \left[\begin{array}{l} \dfrac{e^{-k_2\tau}}{-k_2(k_4-k_2)(k_3-k_2)(k_1-k_2)} + \\ + \dfrac{e^{-k_1\tau}}{-k_1(k_4-k_1)(k_3-k_1)(k_2-k_1)} \end{array}\right] \end{gathered} \tag{19}$$

These equations express the time behaviour of concentration of the starting material (amaranth remnant), intermediate products and the final product (biogas). The equations also enable us to make a simulative calculation of kinetic curves.

The time behaviour of the individual dimensionless concentrations are shown in the following figures:

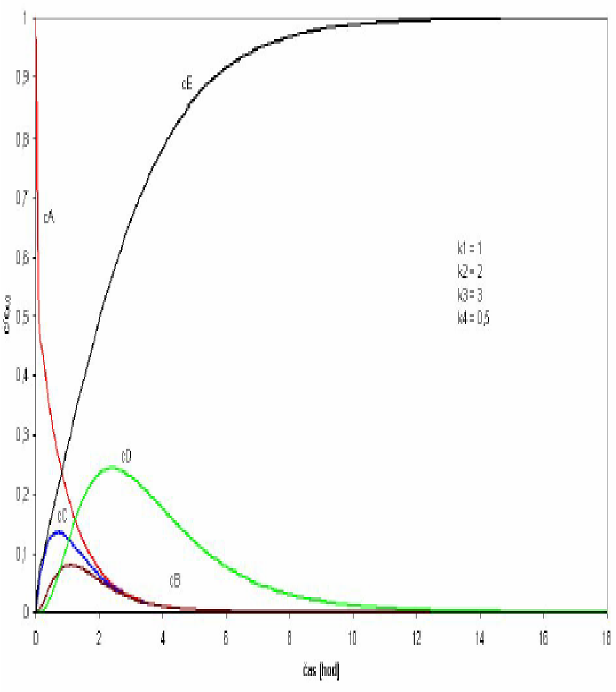

Fig. 1. Time behaviour of the concentriton of starting matherial, intermediate and final product for four-step model

4. Conclusion

As it was said in the introduction, only a little attention is paid to the complex processing of the amaranth mass. In this contribution, anaerobic decomposition of the remnant amaranth mass was dealt with. The resulting very pure biogas shows that the amaranth remnants can be used as a possible alternative energy resource. The complex process of the biogas production was described by four follow-up reactions and the first order for all reactions was assumed for the simulative calculations of the kinetic curves.

References:

[1] Kolomazník, K. at all. *Obtaining proteins from non-traditional sources,* Research Report,, , p. 53, 2005

[2] Kolomazník, K., at all.: *Recovery and recycling of chromium and protein from liquid and solid wastes from leather industry*, ERB 3512 PL 940974 (COP 974) Northampton, 1996

[3] AMR AMARANTH a.s., *Complex utilisation of Amaranth biomass,* Project No. FD – K2/73, 2004

Acknowledgment:

The work was supported by the Ministry of Education of the Czech Republic in the range of the project No. MSM 7088352102