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MODELLING OF TEMPERATURE CONTROL SYSTEM IN FERMENTATION PROCESSES USING GENERALIZED NETS AND INTUITIONISTIC FUZZY LOGICS

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ABSTRACT: A model of temperature control system in fermentation processes based on the apparatus of the generalized nets is developed and presented in this paper. Generalized nets are preliminary proved to be an appropriate tool for description of biotechnological processes biochemical variables. Here we are modelling the temperature control outline in fermentation processes, which allows control feed value in cooling, as well as in heating input channel. Intuitionistic fuzzy logic is also implemented in the developed generalized model in order to reflect the degree of uncertainty which is typical for measurements of biotechnological variables, such as temperature. The application of intuitionistic fuzzy logic leads to the significant decrease of the measurement error influence.

KEYWORDS: Temperature Control Outline, Modelling, Generalized Nets, Intuitionistic Fuzzy Logic

1. INTRODUCTION

Temperature is one of the most influential factors affecting the fermentation process. Temperature affects the growth and activity of all living cells. At high temperatures, organisms are destroyed, while at low temperatures their rate of activity is decreased or even suspended. Micro-organisms can be classified into three distinct categories according to their temperature preference. For example, the classification of bacteria according to temperature requirements is presented in Table 1 [4].

Table 1. - Temperature required for growth per type of bacteria

	Type of bacteria		
Temperature required for growth, ^0C	Psychrophilic	Mesophilic	Thermophilic
minimum	0 to 5	10 to 25	25 to 45
optimum	15 to 20	30 to 40	50 to 55
maximum	30	35 to 50	70 to 90
General sources of bacteria	Water and frozen foods	Pathogenic and non-pathogenic bacteria	Spore forming bacteria from soil and water

The control of fermentation processes (bioreactors), in industrial application, is usually restricted to the regulation of pH and temperature at constant values which are supposed to be favourable to the microbial growth. It should be mentioned, that the desire to control the temperature value depends on the type of micro organisms (Table 1). However, it should be clear that significant performance improvements (in terms of yield and/or productivity) are to be expected from the control of the biological variables themselves (such as biomass, substrate or synthesis product). The following examples are typical:

- regulation of substrate concentration;
- regulation of dissolved oxygen concentration;
- regulation of product concentration;
- regulation of gaseous outflow rates.

The difference of the biological variables mentioned above, the temperature is a variable that should be controlled not only during the cultivation process, as well in the sterilization. The switching between phases, the sterilization phase to the cultivation phase, is connected with the cooling of the culture medium to the temperature of fermentation. Usually the control value for the temperature channel during the cultivation phase is a consumption of the cooling water because the most fermentation processes are exothermal. That kind of control of temperature regime has the following main drawback. When the process passes through the sterilization phase to the cultivation phase it could appear an overcooling of the culture medium that could not be overcame without the availability of a second (heating) channel. Therefore, the temperature control during the fermentation processes is carried out based on an outline which allows feed of control value in cooling, as well as in heating input channel. The common outline for temperature control is presented in Fig. 1 [4]:

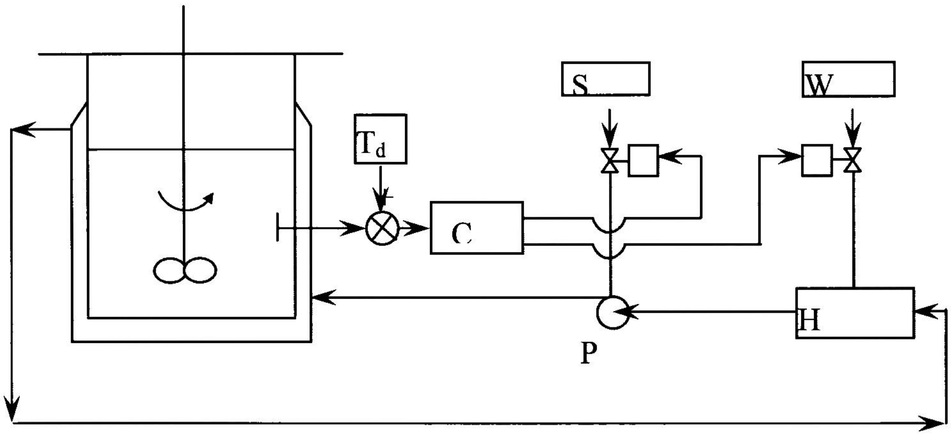

Fig. 1. Outline for temperature control

The following symbols are used:

P – pump for overcoming of the hydraulic strengths;
T_d – desired temperature;
C – controller;
S – steam;
W – water;
H – heat exchanger.

The control is achieved by feeding water in the cooling channel and by feeding steam in the heating channel. To overcome the additional inertness, caused by the heat exchanger, the steam can be also directly feed the circulation outline. In the presented outline for temperature control, PI or PID controllers are usually used that allow a possibility for control of two mechanisms which have antipode actions.

The aim of this paper is to be developed a model of a temperature control system based on the apparatus of the Generalized Nets (GNs) and Intuitionistic Fuzzy Logic (IFL). Up to now GNs were used as a tool for modelling of parallel processes in several areas [2] - economics, transport, medicine, computer technologies, etc. Generalized nets are proved to be an appropriate tool to describe the logic of biotechnological processes [3]. The difference of the models presented in [3] the models that describe the modelling of biological variables (such as biomass, substrate, dissolved oxygen, synthesis of products, etc.) is that in this paper the subject of modelling is the temperature control outline. Intuitionistic fuzzy logic is also implemented in the GN model developed.

2. GENERALIZED NET MODEL OF THE TEMPERATURE CONTROL OUTLINE

The following generalized net model, describing the temperature control outline, is developed (Fig. 2).

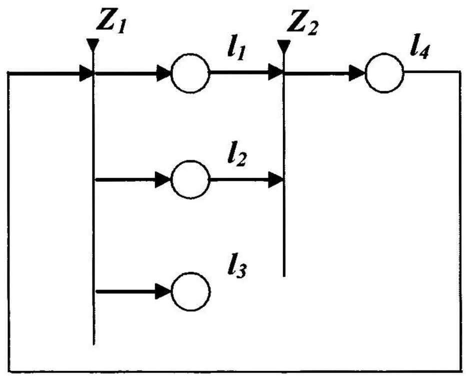

Fig. 2. Generalized net model, describing the temperature control outline

The transition Z_1 is presented as follows:

$$Z_1 = \langle \{l_4\}, \{l_1, l_2, l_3\}, r_1, \square_1 = \wedge (l_4) \rangle$$

$r_1 =$

	l_1	l_2	l_3
l_4	$W_{4,1}$	$W_{4,2}$	$W_{4,3}$

where

$W_{4,1}$ - $T_{mes} > T_{max}$

$W_{4,2}$ - $T_{mes} < T_{min}$

$W_{4,3}$ - $T_{min} \leq T_{mes} \leq T_{max}$

If there is a token in place l_1, which means that the predicate $W_{4,1}$ is true, the cooling channel has to be activated. If there is a token in place l_2, which means that the predicate $W_{4,2}$ is true, the heating channel has to be activated. If there is a token in place l_3, which means that the predicate $W_{4,3}$ is true, than nor water neither steam have to be added.

The transition Z_2 is presented as follows:

$$Z_2 = \langle \{l_1, l_2\}, \{l_4\}, r_2, \square_2 = \vee (l_1, l_2) \rangle$$

r_2 =

	l_4
l_1	true
l_2	true

Presented generalized net model of temperature control system in fermentation processes does not pretend to be comprehensive because it does not describe the action of the used controller (PI or PID). In the future, the proposed generalized net model will be improved with new parts, which will describe the controller action.

3. INTUITIONISTIC FUZZY LOGIC IN THE GN MODEL

The Intuitionistic Fuzzy Sets (IFSs) are defined as extensions of the ordinary fuzzy sets [1]. All results which are valid for the fuzzy sets can be transformed here. Also, all researches, for which the apparatus of the fuzzy sets can be used, can be described in the terms of the IFSs.

Let a set E be fixed. An IFS A in E is an object of the following form:

$$A = \{\langle x, \mu_A(x), \nu_A(x)\rangle \mid x \in E\}, \quad (1)$$

where functions $\mu_A : E \rightarrow [0, 1]$ and $\nu_A : E \rightarrow [0, 1]$ define the degree of membership and the degree of non-membership of the element $x \in E$, respectively, and for every $x \in E$:

$$0 \leq \mu_A(x) + \nu_A(x) \leq 1. \quad (2)$$

Let for every $x \in E$

$$\pi_A(x) = 1 - \mu_A(x) - \nu_A(x). \quad (3)$$

Therefore, function π_A determines the degree of uncertainty.

Usually the desired temperature value in fermentation processes is not a crisp value but belongs to the predetermined interval depending on the considered process. In considered case μ is the degree of appearance of the desired temperature value, ν is the degree of appearance of the temperature values outside the predetermined interval and π is the degree of uncertainty. Let assume that the low boundary of the interval is T_{min} and the upper boundary is T_{max}. Taking into account the error measurement, Δ, the following membership functions are defined:

$$\mu : T_{min} + \Delta \leq T_{meas} \leq T_{max} - \Delta \quad (4)$$

$$\nu : T_{min} - \Delta \geq T_{meas} \geq T_{max} + \Delta \quad (5)$$

$$\pi : (T_{min} - \Delta < T_{meas} < T_{min} + \Delta) \cup (T_{max} - \Delta < T_{meas} < T_{max} + \Delta) \quad (6)$$

Therefore, if the value of measured temperature T_{meas} falls between the limits (4) or (5), then it can be determined unambiguously whether it is a "appropriate temperature" (4) or "inappropriate temperature" (5). The meaning of "appropriate temperature" or "inappropriate temperature" is determined in dependence on considered fermentation processes. Conversely, values that belong to intuitionistic limits (6) can not be unambiguously assigned to one of the two categories.

4. CONCLUSION

Generalized nets, as well as intuitionistic fuzzy logic, were applied here as a new approach for modelling a temperature control system in fermentation processes. Up to the moment generalized nets are proved to be an appropriate tool to describe the logic of biotechnological processes. The difference from the previous author's works where the generalized nets are applied for development of models of biological variables (such as biomass, substrate, dissolved oxygen, synthesis of products, etc.) is that in this paper the subject of modelling is the temperature control outline. The temperature control outline contains of two channels, respectively cooling and heating input channels. The presented generalized net model describes the operations in the temperature control during the fermentation processes and allows the temperature to be kept in the desired interval $[T_{min}, T_{max}]$. This temperature control system should be coupled to bioreactors in order to provide the optimal temperature for cultivation of micro-organisms.

The fuzzification of temperature is presented on the basis of intuitionistic fuzzy logic. Its implementation in the developed generalized model allows us to reflect the degree of uncertainty when the temperature is measured. The application of intuitionistic fuzzy logic leads to the significant decrease of the measurement error influence when the temperature is controlled in the fermentation processes.

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