GENERALIZED NET MODEL OF pH CONTROL SYSTEM IN BIOTECHNOLOGICAL PROCESSES

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Abstract: In this paper a generalized net model of pH control system in biotechnological processes is presented. Generalized nets are preliminary proved to be an appropriate tool for description of the logics of biotechnological process modelling, including the opportunity the biochemical variables of considered processes to be described. The apparatus of the generalized nets allows the possibility for optimal process carrying out. Here generalized nets are applied for modelling of pH control outline in biotechnological processes. The GN model permits to be taken into account the value of pH in the bioreactor. Based on that value the GN model determines what solution (base or acid) have to be added to the bioreactor in order to be controlled the pH value in some desired interval.

Keywords: Generalized Nets, Control, pH

1. INTRODUCTION

pH is one of the most important chemical environmental measurements used to indicate the course of the biotechnological process. It detects the presence of specific chemical factors that influence growth, metabolism, and final product [4]. As it is well-known, the pH of a solution is an indication of its acidic/basic properties and is measured on a scale ranging between 0 and 14. The pH range is presented in Table 1.

Table 1.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Strongly Acidic				*Weakly Acidic*		*Neutral*			*Weakly Basic*			*Strongly Basic*		

Acid-base reactions between components in water solution are normally extremely fast, that is practically in equilibrium at any time. This is the normal presumption for dynamic models. The standard presumption is, however, not fulfilled if the reactions involve species, which are present in solid forms. This is in fact a common case [3].

A solution with a pH<7 is *acidic* and has the following properties:
- The ability to change the color of acid-base indicator (blue to red).
- The ability to release gaseous carbon dioxide when carbonate ions are added.
- The ability to reach with and neutralize a base.
- The ability to reach and dissolve certain metals.

A solution with a pH>7 is *basic* (also referred to as *alkaline*) and has the following properties:
- A "soapy" or slippery feeling to the touch (this is due to the base dissolving a layer of skin).
- The ability to change the color of acid-base indicator (red to blue).
- The ability to reach with and neutralize an acid.
- The ability to form a precipitate when added a solution containing certain metals in solution.

A solution with a pH=7 is considered *neutral* and has neither properties of an acid or a base.

Why monitor and control pH?

Control and monitoring of pH is an important aspect of many industrial biotechnological processes in order to provide the optimal conditions for microorganisms growth. For example, the pH of wastewater treatment is important for the following reasons [4]:

- A low pH can be corrosive to sewer facility components such as pipes, screening equipment and pumps.
- A very low pH or a very high pH can be damaging to the biological activity of a municipal wastewater treatment plant.
- Low pH wastewater has the ability to dissolve large quantities of toxic heavy metals which in turn can be detrimental to the biological life in a municipal wastewater treatment plant.
- Low or high pH wastewater may mix with other industrial wastes within the sewer system forming undesirable by-products such as toxic gases and heavy metal precipitates.

For reasons mentioned above it is very important that the pH of wastewater entering a sewer system has to be maintained within certain limits. Acceptable pH discharge limits may vary depending on permit limitations imposed by your local sewer authority, but are typically within U.S.EPA range of 5 through 10 [4].

Wastewater with a pH outside of acceptable limits will require adjustments prior to discharge. If the solution is too *acidic* a base must be added to raise the pH and if the solution is too *alkaline* an acid must be added to lower the pH. In both cases the adjustment material (acid or base) is referred to as a *reagent* and must be added at a controlled rate so as not to overshoot the desired pH range. Typical pH adjustment reagents used are sulfuric acid and sodium hydroxide. However, use of a particular reagent will depend on the nature of the wastewater.

When adding reagents it is important to understand that a one unit change in pH represents a ten fold change in the effective strength of an acid or base. For example, if 1000 gallons of wastewater requires 10 gallons of a particular reagent to raise its pH from 3 to 4 it will require only one additional gallon of the same reagent to continue to increase its pH from 4 to 5.

As another example of importance of pH for optimal carrying out of biotechnological processes is an influence of pH in penicillin production processes. The pH of commercial mash of penicillin production must be closely monitored and controlled in both the growing phase and the production phase. Early in the growth phase, the pH of the mash is carefully maintained between 4.5 and 5.5, depending on the mash formulation. The range is set to ensure the most favorable condition for growth. The metabolism of glucose and rapid consumption of ammonia during this phase adversely affect the medium by lowering the pH. If the medium is not adjusted, growth may be inhibited and the fermentation may take a long time to reach the optimal range required for penicillin production.

In the production phase, the organism starts to metabolize other sugars (lactose) and amino compounds because of the depletion of glucose. The liberation and accumulation of ammonia from the metabolism of amino compounds will cause the pH to slowly rise. The pH is allowed to rise to about 7 and is controlled at this point until the end of production. Depending on the culture and several other factors, it has been found that the optimum range for penicillin production lies between 6.8 and 7.8. The pH is carefully monitored and controlled in this range by the addition of sulfonic acid. Finally, at the end of the fermentation, the pH rises and production stops [4].

These two examples show the importance of pH monitoring and control at some favorable value in biotechnological processes. Some fundamentals in pH control are [3]:

- The extreme nonlinearity of the strong acid - strong base process does not exist in common industrial surroundings. All process water is buffered. E.g. distilled water in contact with air contains a considerable carbonic-acid buffer with a drastic reduction of nonlinearity compared to the unbuffered system.
- The nonlinearity of a typical pH-control loop (feedback around a stirred tank) is not the main problem. The main problem is the severe performance demand (in terms of concentration) together with performance degrading components (esp. dead times) in the control loop.
- Time-varying buffering is, however, a common source for poor pH control. The solution to time-varying buffering is adaptive control. Adaptive control can be with linear or with nonlinear feedback.

The control loop for pH is well-known, based on adding of base or acid aiming pH to be maintained in some optimal region. In this paper the main purpose is to be developed a generalized net model of pH control system. Until now Generalized Nets (GN) have been used as a tool for the modelling of parallel processes in several areas [1, 2] – economics, transport, medicine, computer technologies, and so on. The idea of using GN for the modelling of biotechnological processes is suggested by the fact that GNs provide the opportunity to describe the logic of the considered processes. The use of GN for the description of biotechnological processes affords the following opportunities [1, 2]:

- on-line control;
- searching of optimal conditions for the process;
- process of learning on the basis of experimental data;
- control on the basis of expert systems.

Up to the moment, the framework of generalized nets is implemented for the modelling of the different operational modes of biotechnological processes, for the different biotechnological processes such as fed-batch fermentations of *E. coli* and *Br. flavul*, as well as for the wastewater treatment processes [6]. On the other hand, generalized nets are used for control of some physics-chemical parameters of biotechnological processes, such as temperature [5].

2. GENERALIZE NET MODEL OF pH CONTROL SYSTEM

The generalized net model, described pH control system, is presented in Fig. 1. As a first application, here the fed-batch operational mode of biotechnological processes is considered. As it has been presented in [6], the GN model developed for fed-batch mode can be easily transformed for batch and continuous mode.

The token α enters GN in place l_1 with an initial characteristic "flow rate of the medium feed". The form of the first transition of the GN model is:

$$Z_1 = \langle \{l_1, l_5\}, \{l_4, l_5\}, r_1, \vee (l_1, l_5) \rangle,$$

$$r_1 = \begin{array}{c|cc} & l_4 & l_5 \\ \hline l_1 & false & true \\ l_5 & W_{5,4} & true \end{array}$$

where $W_{5,4}$ is "need of new concentration of substrate, depending on the value in place l_{12}".
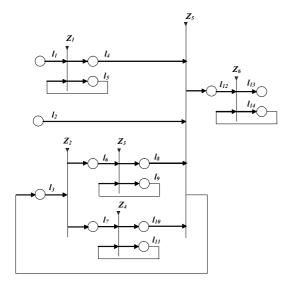
Fig. 1. GN model of pH control system

The token α obtains the characteristics "concentration of the substrate added to the bioreactor" in place l_4, "amount of medium feed in storage" in place l_5.

The token β enters GN in places l_2 with a characteristic "initial concentration of process variables". As process variables could be considered substrate(s), biomass, product(s) etc. The control of pH in the bioreactor is realized by adding base (transition Z_4) or acid (transition Z_3) in dependence on current value of pH (transition Z_2). The token γ enters GN with an initial characteristic "pH in the bioreactor" in place l_3.

The form of the second transition of the GN model is

$$Z_2 = \langle \{l_3\}, \{l_6, l_7\}, r_2, \wedge (l_3) \rangle,$$

$$r_2 = \begin{array}{c|cc} & l_6 & l_7 \\ \hline l_3 & W_{3,6} & W_{3,7} \end{array}$$

where $W_{3,6}$ is "if the value in place l_3 has been increased towards the desired value";
$W_{3,7}$ – "if the value in place l_3 has been decreased towards the desired value".

The token γ obtains the characteristics "amount of acid" in place l_6 and "amount of base" in place l_7. The forms of the third and fourth transitions of the GN model are:

$$Z_3 = \langle \{l_6, l_9\}, \{l_8, l_9\}, r_3, \vee (l_6, l_9) \rangle, \qquad Z_4 = \langle \{l_7, l_{11}\}, \{l_{10}, l_{11}\}, r_4, \vee (l_7, l_{11}) \rangle,$$

$$r_3 = \begin{array}{c|cc} & l_8 & l_9 \\ \hline l_6 & false & true \\ l_9 & W_{9,8} & true \end{array} \qquad r_4 = \begin{array}{c|cc} & l_{10} & l_{11} \\ \hline l_7 & false & true \\ l_{11} & W_{11,10} & true \end{array}$$

where $W_{9,8}$ is "add acid if there is a token in place l_6";
$W_{11,10}$ - "add base if there is a token in place l_7".

The token γ obtains the characteristics:
- in place l_8 - "amount of acid added to the bioreactor";
- in place l_9 - "amount of acid in storage";
- in place l_{10} - "amount of base added to the bioreactor";
- in place l_{11} - "amount of base in storage".

The form of the fifth transition of the GN model is:

$$Z_5 = \langle \{l_2, l_4, l_8, l_{10}\}, \{l_{12}\}, r_5, \square_6 \rangle,$$

$$r_5 = \begin{array}{c|c} & l_{12} \\ \hline l_2 & W_{2,12} \\ l_4 & true \\ l_8 & true \\ l_{10} & true \end{array}$$

$$\square_6 = (\wedge (l_2, l_4), \vee (l_8, l_{10})$$

where $W_{2,12}$ is "start of the process". Tokens α, β and γ are combined in a new token ρ in place l_{12}. The token ρ obtains a characteristic "concentration of process variables".

The form of the sixth transition of the GN model is:
$$Z_6 = <\{l_{12}, l_{14}\}, \{l_{13}, l_{14}\}, r_6, \vee (l_{12}, l_{14})>,$$

$$r_6 = \begin{array}{c|cc} & l_{13} & l_{14} \\ \hline l_{12} & false & true \\ l_{14} & W_{14,13} & W_{14,14} \end{array}$$

where $W_{14,13}$ is "end of the process" and $W_{14,14} = \neg W_{14,13}$.

The token ρ obtains the characteristics:
- in place l_{13} - "concentration of process variables in the end of the process";
- in place l_{14} - "concentration of process variables during the process".

Presented in this way GN model, based on the transitions conditions, allows controlling the pH in some optimal range.

CONCLUSION

A generalized net model of pH control system in biotechnological processes is developed. The proposed GN model permits to control the pH in an appropriate range for concrete biotechnological process. The apparatus of generalized nets allows the description of pH control system. That could be done easily and simple in logics. The GN model, taking into account the value of pH in the bioreactor, determines which reagent should be added to the bioreactor. If the culture medium is acidic, then a base should be infused. Otherwise, if the culture medium is basic, then an acid should be infused. An effective and well controlled pH adjustment system will use as little reagent as possible.

The control of bioreactors in industrial application is usually restricted to the regulation and control of temperature, pH and dissolved oxygen. Up to now the apparatus of generalized nets is applied for control of temperature and pH in biotechnological processes. So, the next logical step will be the development of the generalized net model for dissolved oxygen regulation.

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