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AN APPLICATION OF GENERALIZED NETS FOR MODELLING OF FED-BATCH FERMENTATION PROCESS

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In this paper, Generalized Nets (GNs), are used for modelling of fed-batch fermentation process. Up to now GNs are used as a tool for modelling of parallel processes in several areas [3] - economics, transport, medicine, computer technologies etc.

In the fed-batch process, substrate is added in increments as the fermentation progresses. Thus, the volume of the culture increases with time. The formation of many secondary metabolites is subject to catabolite repression by high concentrations of glucose, other carbohydrates, or nitrogen compounds. Because of this, in the fed-batch fermentation the critical element of the nutrient solution are added in small concentration at the beginning of the fermentation and these substrates continue to be added in small doses during the production phase.

The use of fed-batch by the fermentation industry takes advantage of the fact that residual substrate concentration may by maintained at a very low level in such a system. A low residual level of substrate may be advantageous in:

- Removing repressive effects of rapidly utilised carbon sources and maintaining conditions in the culture within the aeration capacity of the fermentor;
- Avoiding the toxic effects of a medium component.

Considerable increases in productivity have been achieved by the use of computer controlled feeding of glucose during the rapid growth phase, such that the dissolved oxygen (DO) or pH is maintained within certain limits. Both control parameters essentially measure the same activity in that, both oxygen consumption and pH will fall when glucose is in excess, due to an increased respiration rate and the accumulation of organic acid when the respiration rate exceeds

the aeration capacity of the fermentor. Both systems appear to work well in controlling feed rates during the rapid-growth phase [1, 2].

The use of GNs for description of this process afford the following opportunities:

- On-line control;
- Searching of optimal conditions for the fermentation;
- Process of learning on the base of experimental data, [5];
- Control on the base of expert system, [4].

GN model, described fed-batch fermentation process, is presented in Fig. 1.

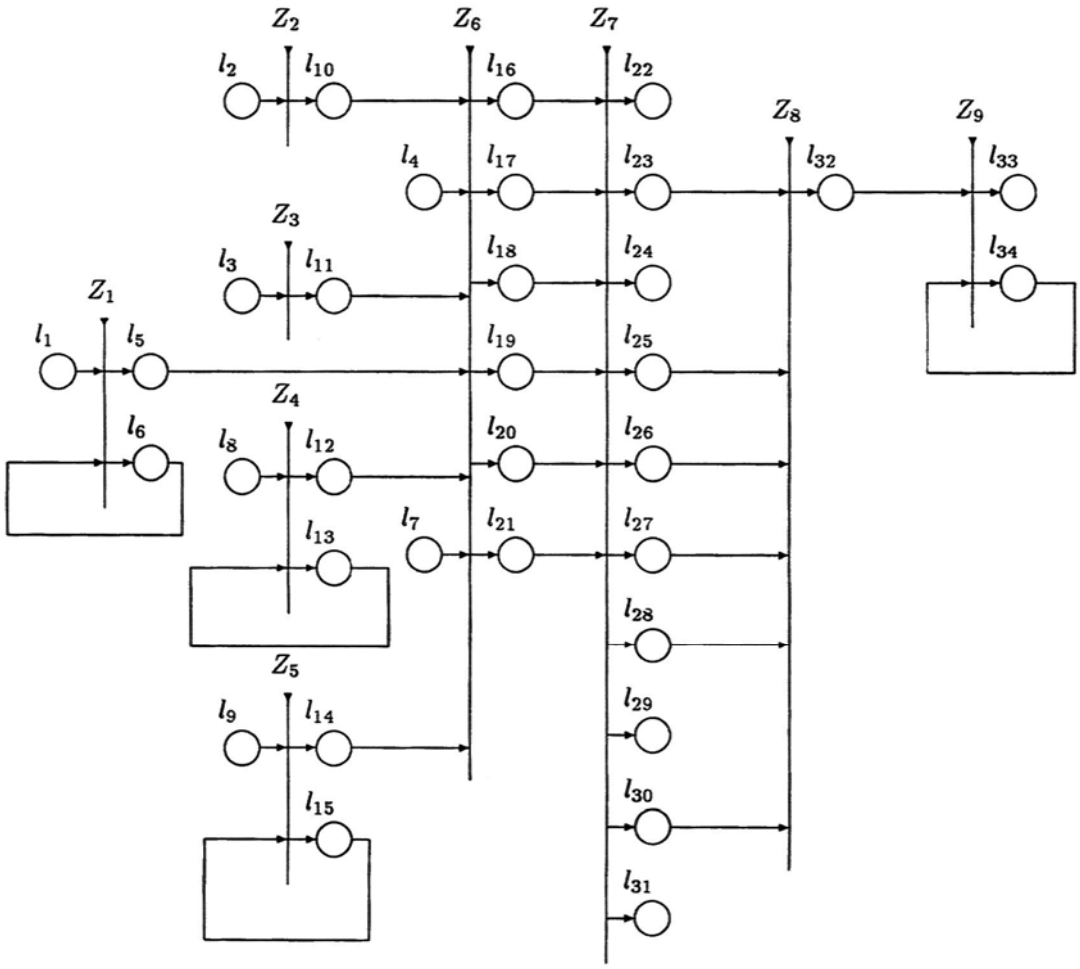

Fig. 1 GN model, described fed-batch fermentation process

The token α enters GN in place l_1 with an initial characteristic “flow rate of the medium feed”.

$$Z_1 = <\{ l_1, l_6 \},\{ l_5, l_6 \},\ r_1 = \begin{array}{c|cc} & l_5 & l_6 \\ \hline l_1 & \text{false} & \text{true} \\ l_6 & W_{6,5} & \text{true} \end{array},\ \square_1 = \vee(l_1, l_6) >,$$

where $W_{6,5}$ - “new concentration of substrate, on the dependence of value in position l_{26}”.

The token obtains the characteristics “concentration of the substrate added to the fermentor” in place l_5, “amount of medium feed in storage” in place l_6 and “concentration of the substrate in the fermentor” in place l_{26}.

The token β enters GN in place l_2 with an initial characteristic “oxygen”.

$$Z_2 = <\{ l_2 \},\{ l_{10} \},\ r_2 = \begin{array}{c|c} & l_{10} \\ \hline l_2 & W_{2,10} \end{array},\ \square_2 = \wedge(l_2, l_{22}, l_{23}) >,$$

where $W_{2,10}$ - “new concentration of oxygen, on the dependence of value in position l_{23} and existence of a token in place l_{22}”.

The token obtains the following characteristics:

Place l_{10} - “concentration of oxygen added to the fermentor”;

Place l_{22} - “control of concentration of dissolved oxygen by oxygen flow rate”;

Place l_{23} - “concentration of the oxygen in the fermentor”.

The token γ enters GN with an initial characteristic “oxygen” in place l_3.

$$Z_3 = <\{ l_3 \},\{ l_{11} \},\ r_3 = \begin{array}{c|c} & l_{11} \\ \hline l_3 & W_{3,11} \end{array},\ \square_3 = \wedge(l_3, l_{23}, l_{24}) >,$$

where $W_{3,11}$ - “choose a new rotation speed of stirrer, on the dependence of value in position l_{23} and existence of a token in place l_{24}”.

The token obtains the following characteristics:

Place l_{11} - “ rotation speed of stirrer”;

Place l_{24} - “control of dissolved oxygen concentration by the rotation speed’ variation”.

The token ε enters GN with an initial characteristic “amount acid” in place l_8.

$$Z_4 = <\{ l_8, l_{13} \},\{ l_{12}, l_{13} \}, r_4 = \begin{array}{c|cc} & l_{12} & l_{13} \\ \hline l_8 & \text{false} & \text{true} \\ l_{13} & W_{13.12} & \text{true} \end{array}, \square_4 = \vee(l_8, l_{13}) >,$$

where $W_{13,12}$ - “add acid, on the dependence of value in position l_{30} and existence of a token in place l_{29}”.

The token obtains the characteristics “concentration of acid added to the fermentor” in place l_{12}, “amount of acid in storage” in place l_{13} and “high value of pH in the fermentor” in place l_{26}.

The token δ enters GN with an initial characteristic “amount base” in place l_9.

$$Z_5 = <\{ l_9, l_{15} \},\{ l_{14}, l_{15} \}, r_5 = \begin{array}{c|cc} & l_{14} & l_{15} \\ \hline l_9 & \text{false} & \text{true} \\ l_{15} & W_{15,14} & \text{true} \end{array}, \square_5 = \vee(l_9, l_{15}) >,$$

where $W_{15,14}$ - “add base, on the dependence of value in position l_{30} and existence of a token in place l_{31}”.

The token obtains the characteristics “concentration of base added to the fermentor” in place l_{14}, “amount of base in storage” in place l_{15} and “low value of pH in the fermentor” in place l_{31}.

The tokens φ and η enter GN in places l_4 and l_7 respectively, with characteristics “initial concentration of the substrate” and “initial concentration of the biomass”.

$Z_6 = <\{ l_4, l_5, l_7, l_{10}, l_{11}, l_{12}, l_{14}\},\{ l_{16}, l_{17}, l_{18}, l_{19}, l_{20}, l_{21}\}, r_6, \square_6 >$

The tokens obtain the following characteristics:

Token β in place l_{16} - “concentration of dissolved oxygen in the fermentor”;

Token γ in place l_{17} - “rotation speed of stirrer in the fermentor”;

Token φ in place l_{18} - “concentration of the substrate in the fermentor”;

Token α in place l_{19} – “fermentor volume”;

Token η in place l_{20} - “concentration of the biomass in the fermentor”.

Tokens ε and δ are combined in place l_{21} and the new token obtains characteristic “pH in the fermentor”.

r_6 =

	l_{16}	l_{17}	l_{18}	l_{19}	l_{20}	l_{21}
l_4	false	false	true	false	false	false
l_5	false	false	true	true	false	false
l_7	false	false	false	false	true	false
l_{10}	true	false	false	false	false	false
l_{11}	false	true	false	false	false	false
l_{12}	false	false	false	true	false	true
l_{14}	false	false	false	true	false	true

$\square_6 = (\wedge(l_4, l_5, l_7), \vee(l_{10}, l_{11}), \vee(l_{12}, l_{14}))$

The form of the seventh transition condition of the GN-model is:

$Z_7 = <\{l_{16}, l_{17}, l_{18}, l_{19}, l_{20}, l_{21} \},\{l_{22}, l_{23}, l_{24}, l_{25}, l_{26}, l_{27}, l_{28}, l_{29}, l_{30}, l_{31} \}, r_7, \square_7 >$

r_7 =

	l_{22}	l_{23}	l_{24}	l_{25}	l_{26}	l_{27}	l_{28}	l_{29}	l_{30}	l_{31}
l_{16}	$W_{16,22}$	true	$W_{16,24}$	false	false	false	false	false	false	false
l_{17}	false	false	false	true	false	false	false	false	false	false
l_{18}	false	false	false	false	true	false	false	false	false	false
l_{19}	false	false	false	false	false	true	false	false	false	false
l_{20}	false	false	false	false	false	false	true	false	false	false
l_{21}	false	false	false	false	false	false	false	$W_{21,29}$	true	$W_{21,31}$

$W_{21,29}$ – “high pH in the fermentor”, $W_{21,31}$ – “low pH in the fermentor”.

$\square_7 = \wedge(l_{16}, l_{17}, l_{18}, l_{19}, l_{20}, l_{21})$

After the transition all tokens keep the same characteristics.

The form of the eighth transition condition of the GN-model is:

$Z_8 = <\{ l_{23}, l_{25}, l_{26}, l_{27}, l_{28}, l_{30} \},\{ l_{32} \}, r_8, \square_8 = \wedge(l_{23}, l_{25}, l_{26}, l_{27}, l_{28}, l_{30}) >$

r_8 =

	l_{32}
l_{23}	true
l_{25}	true
l_{26}	true
l_{27}	true
l_{28}	true
l_{30}	true

All tokens are combined in one token with characteristic in place l_{32} “concentration of dissolved oxygen, rotation speed, concentration of the substrate, volume, concentration of the biomass, pH”.

$$Z_9 = <\{ l_{32}, l_{34} \}, \{ l_{33}, l_{34} \}, r_9 = \begin{array}{c|cc} & l_{33} & l_{34} \\ \hline l_{32} & \text{false} & \text{true} \\ l_{34} & W_{34,33} & W_{34,34} \end{array}, \Box_9 = \vee(l_{32}, l_{34}) >,$$

where $W_{34,33}$ – “end of the process” and $W_{34,34} = \neg W_{34,33}$.

The token obtains the characteristics “concentration of dissolved oxygen, rotation speed, concentration of the substrate, volume, concentration of the biomass, pH” in the end of the process in place l_{33} and “concentration of dissolved oxygen, rotation speed, concentration of the substrate, volume, concentration of the biomass, pH” during the process in place l_{34}.

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