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Phasing Model of Penicillin Ferment Process by Type-2 Fuzzy System

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Abstract: In this paper, the penicillin production process model is established by type-2 fuzzy system. Furthermore, the model is melt with the expert knowledge and experience. According to the trend of thallus density S and its rateS', the orbit figure of density changing and attenuation of penicillin is given. Integrate with the former process, the type-2 fuzzy model is established. It could supply sustained locus from growing and breeding, until penicillin combining produces speed. In this model, only part of experience for penicillin ferment is needed. Thus, it can set up the input-output model easily. Moreover, it can reach better approach result.

Keywords:type-2 fuzzy system; penicillin; model ;simulation

1 Introduction

The fermentation process is a non-linear and uncertain system with great complexity [1]. Current system dynamic models generally deal with multi-feedback, non-linear, time-dependent ecosystems with uncertainties, which make the relations of variables in a causality chain rather vague [2]. In fact, most experts use natural language and qualitative reasoning to describe the complicated experience in ferment process, instead of adopting differential equations or analysis model. Hence, the methods of input-output based neural network or fuzzy system are generally introduced in describing the biological evolution process. Zadeh put forward the fuzzy set theory [3], which becomes an effective way to analyze natural language knowledge[4], and provides great assistance in expert knowledge problems. Regulations match the expressions of experts to complicated projects. Paper [5] established the parameter-based and status variables-based T-S fuzzy model to shape the fed-batch ferment process; Jun-Ichi Horiuchi reviewed the successful applications of Type-1 fuzzy system in fermentation [6]. However, when the system complexity increases, Type-1 fuzzy system is hard to control. [7] put forward the Type-2 fuzzy system, with strong expressiveness in complicated uncertain systems. The fuzzy set enjoys three-dimensional characters, and the membership function contains "broad band" properties to handle the uncertainties in system. In this paper, according to the trend of thallus density S and its rateS', the orbit figure of density changing and attenuation of penicillin is given. Integrate with the former process, the type-2 fuzzy model is established. It could supply sustained locus from growing and breeding, until penicillin combining produces speed. In this model, only part of experience for penicillin ferment is needed and it can set up the input-output model easily. Moreover, it can reach better approach result.

2 The Type-2 Fuzzy Model in Penicillin Fermentation

The ferment process contains three periods, namely the prophase, metaphase and anaphase: the prophase is the time for thallus growth, fermentation medium get the vaccination in suitable environment, and embrace the development, growth and reproduction until it reaches a critical concentration; second period is the synthesis of penicillin, the production speed reaches a maximum value within it and generally evolves until the production ability recesses; the last period is the bacteria autolysis, with the aging of bacteria and the autolysis of cells, the fermentation process must come to an end at this time

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to prevent the possible damage to penicillin and difficulty in ferment broth and refining works. Main factors affecting the ferment production rate are : pH value $[6.5, 6.8]$; dissolved oxygen$[0.032 \times 30\%, 0.032]$.

2.1 Expert knowledge in penicillin fermentation process

(1) Try to avoid pH exceeds over7.0 in ferment process, as penicillin becomes unstable in alkaline condition and accelerate hydrolysis; if the rate of fed-batch comes too high, the accumulation of acid intermediates can cause the decease in pH.
(2) When the dissolved oxygen concentration declines to 30% below, the production rate of penicillin declines sharply, when it comes to 10% below, irreversible damage occurs. Excessive concentration demonstrates that unhealthy bacteria growth affect the production ability.
(3) Important parameters: critical mycelium density:8.1; critical production rate:0.015.

2.2 The Model of Type-2 in different periods:

(1) Thallus Growth Period
Step1 Build the Type-2 membership functions for main factors.
pH: Low(L); Middle(M);High(H),with fuzzy sets corresponding to L,M,H and Type-2 membership function as follows:

$$\mu_L(x_k) = \exp[-\frac{1}{2}(\frac{x_k - m_k^{'}}{\delta})^2] \quad m_k^{'} \in [6.0, 6.5], \delta = 0.5$$

$$\mu_M(x_k) = \exp[-\frac{1}{2}(\frac{x_k - m_k^{'}}{\delta})^2] \quad m_k^{'} \in [6.5, 6.8], \delta = 0.3$$

$$\mu_H(x_k) = \exp[-\frac{1}{2}(\frac{x_k - m_k^{'}}{\delta})^2] \quad m_k^{'} \in [6.8, 7.0], \delta = 0.2$$

Dissolved Oxygen(O): Low(L); Middle(M);High(H),with Type-2 membership function as follows

$$\mu_L(x_k) = \exp[-\frac{1}{2}(\frac{x_k - m_k^{'}}{\delta})^2] \quad m_k^{'} \in [0.0064, 0.0096], \delta = 0.0032$$

$$\mu_M(x_k) = \exp[-\frac{1}{2}(\frac{x_k - m_k^{'}}{\delta})^2] \quad m_k^{'} \in [0.0096, 0.0192], \delta = 0.0096$$

$$\mu_H(x_k) = \exp[-\frac{1}{2}(\frac{x_k - m_k^{'}}{\delta})^2] \quad m_k^{'} \in [0.0192, 0.032], \delta = 0.00128$$

S(Thallus)Low (L); Middle (M);High (H),with Type-2 membership function as follows

$$\mu_L(x_k) = \exp[-\frac{1}{2}(\frac{x_k - m_k^{'}}{\delta})^2] \quad m_k^{'} \in [2.5, 8], \delta = 5.5$$

$$\mu_H(x_k) = \exp[-\frac{1}{2}(\frac{x_k - m_k^{'}}{\delta})^2] \quad m_k^{'} \in [8, 8.5], \delta = 0.5$$

$S^{'}$ Thallus production rate: Low(L); High(H).

$$\mu_L(x_k) = \exp[-\frac{1}{2}(\frac{x_k - m_k^{'}}{\delta})^2] \quad m_k^{'} \in [0, 0.015], \delta = 0.015$$

$$\mu_H(x_k) = \exp[-\frac{1}{2}(\frac{x_k - m_k^{'}}{\delta})^2] \quad m_k^{'} \in [0.015, 0.02], \delta = 0.005$$

Step2 Fuzzy regulations by experience
If pH is L and O is L then S is L and S' is L;
If pH is M and O is M then S is H and S' is H;
If pH is Hand O is H then Sis M and S'is L;
Step3 Build the Type-2 Fuzzy System

The steps of designing the type-2 fuzzy system are shown in Figure1:

Type in input variables $x' = \{x'_1, \cdots, x'_p\}$

Fuzzify $x'$by adopting either centre fuzzification or single-point fuzzification, get a type-2 fuzzy set $\tilde{X}'$, and conduct synthesis calculation by inputting fuzzy set and fuzzy relations in the process.

Conduct type-reduction to the of type-2 fuzzy set, centroid reduction, height reduction or centre reduction is available, and put forward a type-1 fuzzy set.(Type-reduced Set)

Defuzzify the type-reduced set and get the accurate output result.

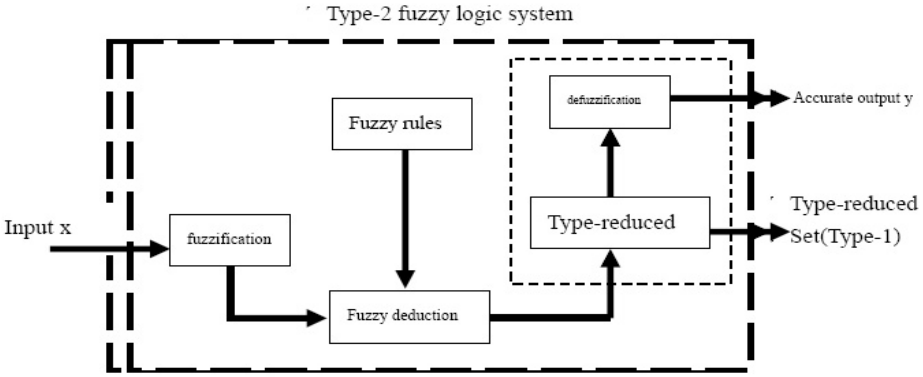


Fig.1. schematic plan of Type-2 fuzzy logic system

Based on design method of Type-2 fuzzy system [7]: this paper adopts the interval type-2 fuzzy system to simplify the calculation, and the result is a type-1 fuzzy set regardless of the "type-reduced" method, with the two extreme points achievable [8, 9]. Hence, the output can be presented as an average value of the extreme points, that is:

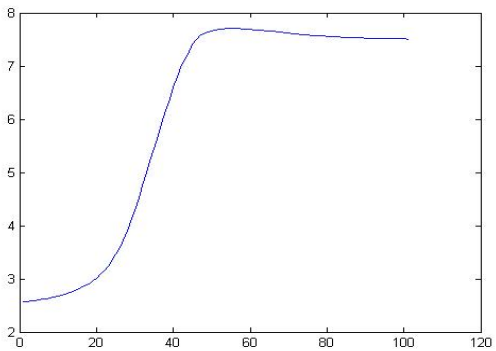
$$\hat{S} = [S_l, S_r] = \int_{s^1} \cdots \int_{s^m} \int_{f^1} \cdots \int_{f^m} 1 \Big/ \frac{\sum_{i=1}^{m} f^i s^i}{\sum_{i=1}^{m} f^i}$$

$$S_l = \int_{s^l} \cdots \int_{s^m} \int_{f^l} \cdots \int_{f^l} 1 / \frac{\sum_{i=1}^{m} \underline{f}^i s^i}{\sum_{i=1}^{m} \underline{f}^i}; S_r = \int_{s^l} \cdots \int_{s^m} \int_{f^l} \cdots \int_{f^l} 1 / \frac{\sum_{i=1}^{m} \bar{f}^i s^i}{\sum_{i=1}^{m} \bar{f}^i}$$

$$S = \frac{S_l + S_r}{2}$$

Here:$f^i \in F^i = [\underline{f}^i, \overline{f}^i]$,$\underline{f}^i = \underline{\mu}_{\tilde{A}_1}(x_1) * \cdots * \underline{\mu}_{\tilde{A}_n}(x_n)$,$\bar{f}^i = \bar{\mu}_{\tilde{A}_1}(x_1) * \cdots * \bar{\mu}_{\tilde{A}_n}(x_n)$

The membership function can be given in step1.The trend of thallus density S and its rateS' are shown as follows (Figure2-3).



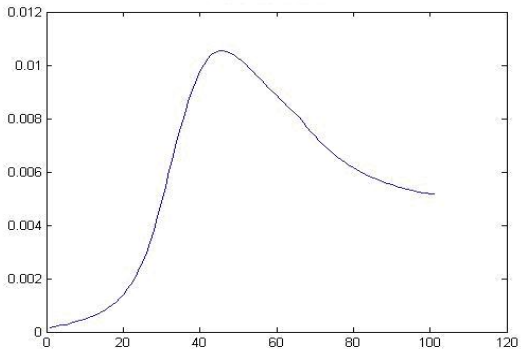


Fig.2. Orbit diagram of thallus productivity

Fig.3. Orbit diagram of growth rate S'

(2) The synthesis period of penicillin

Step1 Build the Type-2 membership function of main factors

pH: Low(L); Middle(M);High(H),with fuzzy sets corresponding to L,M,H and Type-2 membership function as follows:

$$\mu_L(x_k) = \exp[-\frac{1}{2}(\frac{x_k - m_k^{'}}{\delta})^2] \quad m_k^{'} \in [6.0, 6.5], \delta = 0.5$$

$$\mu_M(x_k) = \exp[-\frac{1}{2}(\frac{x_k - m_k^{'}}{\delta})^2] \quad m_k^{'} \in [6.5, 6.8], \delta = 0.3$$

$$\mu_H(x_k) = \exp[-\frac{1}{2}(\frac{x_k - m_k^{'}}{\delta})^2] \quad m_k^{'} \in [6.8, 7.0], \delta = 0.2$$

Dissolved Oxygen (O): Low (L); Middle(M);High(H),with Type-2 membership function as follows

$$\mu_L(x_k) = \exp[-\frac{1}{2}(\frac{x_k - m_k^{'}}{\delta})^2] \quad m_k^{'} \in [0.0064, 0.0096], \delta = 0.0032$$

$$\mu_M(x_k) = \exp[-\frac{1}{2}(\frac{x_k - m_k^{'}}{\delta})^2] \quad m_k^{'} \in [0.0096, 0.0192], \delta = 0.0096$$

$$\mu_H(x_k) = \exp[-\frac{1}{2}(\frac{x_k - m_k^{'}}{\delta})^2] \quad m_k^{'} \in [0.0192, 0.032], \delta = 0.00128$$

P (Penicillin Concentration): Low (L); Middle (M);High (H)

$$\mu_L(x_k) = \exp[-\frac{1}{2}(\frac{x_k - m_k^{'}}{\delta})^2] \quad m_k^{'} \in [8.1, 8.3], \delta = 0.2$$

$$\mu_M(x_k) = \exp[-\frac{1}{2}(\frac{x_k - m_k^{'}}{\delta})^2] \quad m_k^{'} \in [8.3, 8.4], \delta = 0.1$$

$$\mu_H(x_k) = \exp[-\frac{1}{2}(\frac{x_k - m_k^{'}}{\delta})^2] \quad m_k^{'} \in [8.4, 8.5], \delta = 0.1$$

Step2 Fuzzy regulations by experience

If pH is L and O is L then P is L;

If pH is M and O is M then P is H;

If pH is H and O is H then P is M;

Step3 Build the Type-2 Fuzzy system

Similar to the method mentioned above, the change of penicillin production is demonstrated in Figure4.

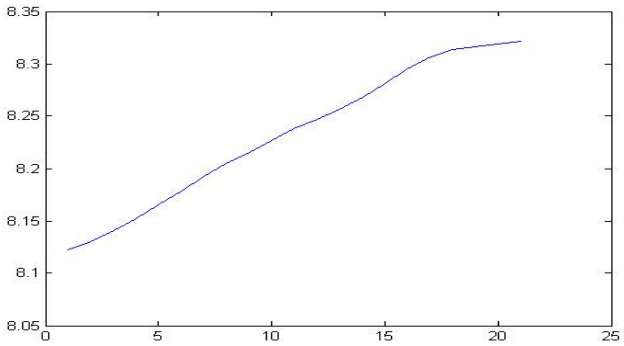


Fig.4. Orbit diagram of penicillin $P^{'}$

(3) Autolysis period of penicillin

Step1 Build the Type-2 membership function of main factors

S: Low(L); Middle(M);High(H),with fuzzy sets corresponding to L,M,H and Type-2 membership function as follows:

$$\mu_L(x_k) = \exp[-\frac{1}{2}(\frac{x_k - m_k^{'}}{\delta})^2] \quad m_k^{'} \in [7,8], \delta = 1$$

$$\mu_M(x_k) = \exp[-\frac{1}{2}(\frac{x_k - m_k^{'}}{\delta})^2] \quad m_k^{'} \in [8,8.5], \delta = 0.5$$

$$\mu_H(x_k) = \exp[-\frac{1}{2}(\frac{x_k - m_k^{'}}{\delta})^2] \quad m_k^{'} \in [8.5.9], \delta = 0.5$$

$S^{'}$ Low (L); Middle (M);High(H),with fuzzy sets corresponding to L,M,H and Type-2 membership function as follows:

$$\mu_L(x_k) = \exp[-\frac{1}{2}(\frac{x_k - m_k^{'}}{\delta})^2] \quad m_k^{'} \in [-0.015, 0], \delta = 0.015$$

$$\mu_M(x_k) = \exp[-\frac{1}{2}(\frac{x_k - m_k^{'}}{\delta})^2] \quad m_k^{'} \in [-0.02, -0.015], \delta = 0.005$$

$$\mu_H(x_k) = \exp[-\frac{1}{2}(\frac{x_k - m_k^{'}}{\delta})^2] \quad m_k^{'} \in [-0.03, -0.02], \delta = 0.01$$

PLow (L); Middle (M); High (H),with fuzzy sets corresponding to L,M,H and Type-2 membership function as follows:

$$\mu_L(x_k) = \exp[-\frac{1}{2}(\frac{x_k - m_k^{'}}{\delta})^2] \quad m_k^{'} \in [5,7], \delta = 2$$

$$\mu_M(x_k) = \exp[-\frac{1}{2}(\frac{x_k - m_k^{'}}{\delta})^2] \quad m_k^{'} \in [7,8.1], \delta = 1.1$$

$$\mu_H(x_k) = \exp[-\frac{1}{2}(\frac{x_k - m_k^{'}}{\delta})^2] \quad m_k^{'} \in [8.1,8.5], \delta = 0.4$$

Step2 Fuzzy rules by experience

If S is H and $S^{'}$ is L then P is H;

If S is M and $S^{'}$ is M then P is M;

If S is L and $S^{'}$ is H then P is L;

Step3 Build the Type-2 Fuzzy system

Similar to the method mentioned above, the change of concentration in penicillin synthesis process is demonstrated in Figure5.

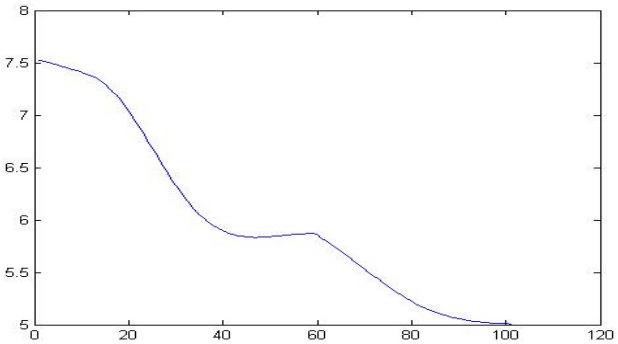


Fig.5. Orbit diagram of penicillin P

3 Integrated modeling from growth to syntheses process of penicillin

According to expert experience, the hyphae density must be controlled under a critical threshold; at the same time, maximum speed of growth should be maintained in the ferment process, with a value higher than 0.015h-1. The fuzzy rules are given:

If S is L and $S^{'}$ is L then P is L;

If S is M and $S^{'}$ is M then P is M;

If S is H and $S^{'}$ is H then P is H;

Here L, M, H are all fuzzy sets of Type-2 system, with the given membership function defined above. The change of penicillin concentration in growth and synthesis period of thallus are shown in Figure6.

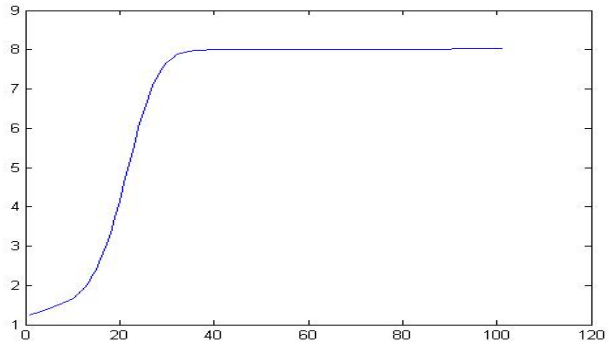


Fig.6. Orbit diagram of penicillin P in growth and synthesis period

4 Integrated modeling in ferment process of penicillin

According to expert experience, the hyphae density must be controlled under a critical threshold; at the same time, maximum speed of growth should be maintained in the ferment process, with a value higher than 0.015h-1. The fuzzy rules are given:

If S is L and $S^{'}$ is L(up) then P is L;

If S is M and $S^{'}$ is M(up) then P is M;

If S is H and $S^{'}$ is H(up) then P is H;

If S is H and $S^{'}$ is L(down) then P is H;

If S is M and $S^{'}$ is M(down) then P is M;

If S is L and $S^{'}$ is H(down) then P is L;

Here L, M, H are all fuzzy sets of Type-2 system, with the given membership function defined above. The change of penicillin concentration in ferment process is shown in Figure7.

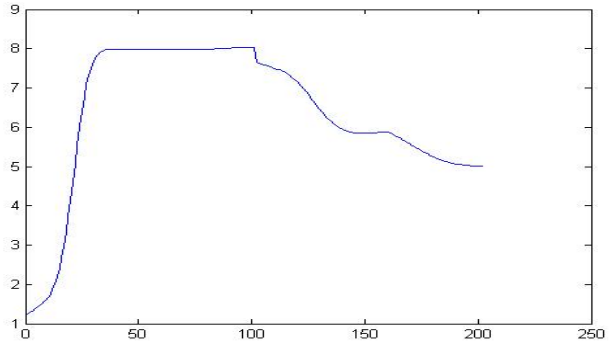


Fig.7. Orbit diagram of penicillin P in ferment process

5 Conclusion

According to three period of penicillin ferment process, namely bacteria growth period, penicillin synthesis period and thallus autolysis period, the membership functions and fuzzy rules are built combing expert experience. Four Type-2 fuzzy models are defined to describe the orbit diagram of critical concentration in various periods, the orbit diagram of penicillin from synthesis to production recession period, and the orbit diagram of production recession period after thallus autolysis and bacteria aging. Fuzzy models simulate the penicillin ferment process and solve some difficulties including immeasurable issues. Only part of experience for penicillin ferment is needed in modeling. Thus, it can set up the input-output model easily and reach better approach result. This also provides an innovative alternate way for fuzzy modeling in biological ferment process with great significance.

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