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Application of Computer Surveillance Technology in Industrial Ethanol Fermentation

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The industrial ethanol fermentation is subjected to complex factors. The evolving computer surveillance technology can optimize fermentation conditions for maximum yield. This paper describes the implementation of computer control technology in the industrial ethanol fermentation process, along with the process dynamics principle. As for the surveillance system which includes hardware and software, it enables the auto environment control of the fermenter without manual intervention, field data acquisition and treatment on the fermentation with the aid of the computer. Subsequently, it greatly optimizes the productivity of ethanol fermentation. Some factors such as the number and activity of yeast cells in the process, the role of substrates, and the formation amount of ethanol dominate the fermentation process.

1. Introduction

The fermentation industry with a long history has established itself as the basis of bioengineering and biochemical engineering. In recent decades, the ethanol fermentation industry has evolved dramatically and ushered people into a flourishing age (Carotenuto et al., 2016; Haringa et al., 2018; Zlatkova and Lyubenova, 2017). Especially in the new biochemical engineering field, industrial ethanol fermentation has aroused wide concern in the tech world, industrial circles and government sectors (Palacios-Bereche et al., 2014; Halder et al., 2016). For a giant fermentation system, improper operation will cause substantial losses to economy. In this sense, how to achieve the parameter measurement, operation supervision, automatic control, operation optimization and control in the industrial ethanol fermentation process has posed the great challenge in the face of optimal management and automation of biochemical reaction process (Ashok and Kumar, 2017). Beyond that, the rapid development of computer technology contributes to advanced automation for biochemical engineering survey, analysis and control processes (Sansonetti et al., 2011; Ho et al., 2016). Now it is certain that the computer control technology will enable auto real-time control, management and optimization of the fermentation process to fill the gaps of available technologies such as unstable fermentation, low coefficient, high energy consumption and high cost (Guan, 2015; Skupin and Metzger, 2017; Seddak and Liazid, 2016).

It is important for us to realize a favorable environment control over the industrial ethanol fermentation process, including ambient temperature, pH value, dissolved oxygen concentration, defrothing, substrate feed, etc. (Cai et al., 2014). As we know, computer storage and supercomputing capacities can optimize and control the industrial ethanol fermentation processes (Ranjbar et al., 2013). This process is a biochemical reaction with highly complex mechanism, it is awkward to describe it with mathematical models available in the industry. Poor recurrence of production experiment data makes a mess of mathematical modeling, while the application of the computer technology has provided great support for the measurement of fermentation parameters, data management and analysis, as well as optimization control of the fermentation process (Zou et al., 2012). This paper probes into the industrial ethanol fermentation process by means of computer technology, and develops a computer control system for industrial ethanol fermentation process.

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2. Control system architecture

2.1 Parameter detection during fermentation

To effectively operate and control the industrial ethanol fermentation, it is required to accurately measure the parameters for it (Ahaotu et al., 2017). The fermentation tank measurement system is shown in Fig. 1, where there are physical parameters (temperature, pressure, air flow, volume of fermentation broth, etc.), biological parameters (biomass concentration, metabolite concentration, substrate concentration, etc.), chemical parameters (fermentation broth pH, dissolved oxygen concentration). Among them, temperature, pH value of fermentation broth and dissolved oxygen concentration are the most important factors that affect ethanol fermentation. As shown in Fig. 2, the curve of the microbiological production in the ethanol fermentation process is plotted. In the whole process, there are four phases occurred, i.e. hysteresis period, logarithmic phase, stationary phase and death phase.

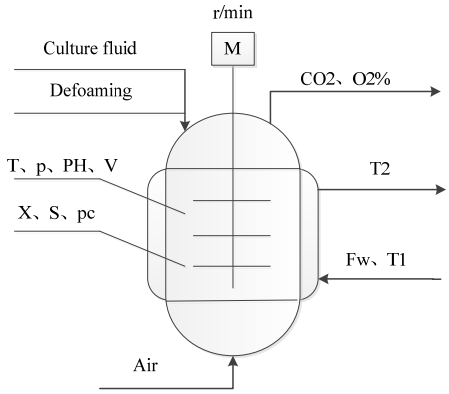

Figure 1: Fermenter measuring system

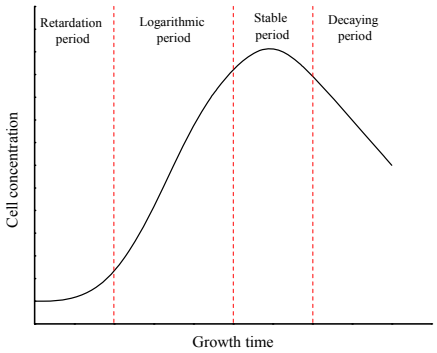

Figure 2: Microbial production curve for ethanol fermentation

2.2 Design of control system

In the complex fermentation process for industrial ethanol, there is a bulk volume of the fermenter generally amount to several hundred or several thousand liters. A mechanical agitator is used to fully mix the air and the fermentation broth to augment the oxygen required for the fermentation. There is a traditional fermenter control system composed of 4 control and 4 measurement parts, of which the former 4 control parts (pH, temperature, defrothing and stirring speed) all adopt closed-loop control mode (Mareš et al., 2016). The temperature closed-loop control block scheme is shown in Fig. 3. With given temperature parameter, the controller sends a control signal. Actuator performs heating or cooling in the fermenter, and the temperature detection is signaled to the controller. This is a closed control loop. As shown in Fig. 4, the relationship between respiratory intensity and dissolved oxygen is given. There is a critical oxygen. Once exceeded, the respiratory intensity will remain unchanged. However, the critical concentration of dissolved oxygen during each fermentation period varies greatly. Therefore, it is unlikely to characterize the critical concentration with a certain oxygen.

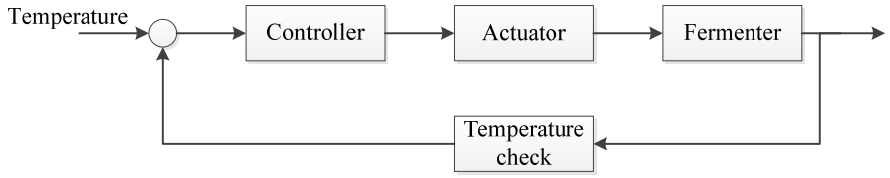

Figure 3: Temperature closed-loop control block diagram

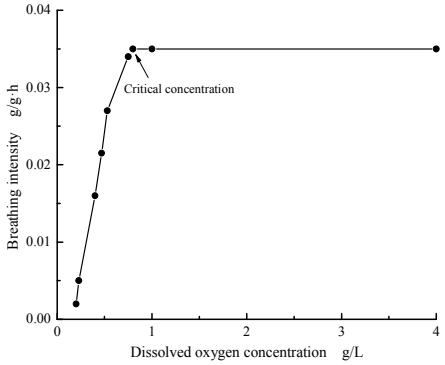

Figure 4: Relationship between respiratory intensity and dissolved oxygen concentration

3. Design of ethanol fermentation control system

3.1 Hardware design

In this experiment, the fermenter control system adopts PLC as a slave computer which enables the collection, treatment and output for various parameters. The hardware equipment for the ethanol production fermentation control system includes pH meter, dissolved oxygen meter, PLC slave computer, and hardware circuit. PH meter adopts GKF type pH sensing system resistant to high-temperature, as small in size, less wired, it is easy to debug. Dissolved Oxygen Meter (DOM) integrates measurement and signal conversion processes. It can toggle between different units of measurement whenever needed to achieve the limit, proportional pulse width and frequency control modes. DOM has its own storage backup capacity. After power loss, correction data and other information will not be deleted. PLC is an editable logic controller in the fermenter control system that can fit the bill for fermenter automation. A sensor, voltage or current source, and a zero signal are added to an input terminal.

3.2 Software design

The software for the computer control system includes two parts, i.e. the data storage and treatment of the host computer, and the data acquisition and loop control of the slave computer. The PLC slave computer is directly connected to the test device which check data such as temperature, pH, and dissolved oxygen reciprocally. The host and slave computers are directly interconnected to perform data acquisition and oversight in real time. In the industrial ethanol fermentation process, the temp control system should be required to track some given parameters for its variation quickly, small overshoot, and without residual error. The control algorithm is shown in Eqs. 1 and 2:

$$\Delta U_k = K_I E_K - K_c E_{K-1} + \Delta UD_K \quad (1)$$

$$\Delta UD_K = \alpha \cdot \Delta UD_{K-1} + (1-\alpha)(K_1 E_K - K_2 E_K + K_3 E_{K-2}) \quad (2)$$

Where:

$$\Delta U_k = U_k - U_{k-1} \quad (3)$$

$$K_I = K_c(1+Ts/Ti) \quad (4)$$

$$K_1 = K_c(1+Td/Ts) \quad (5)$$

$K_2 = K_c(1+2Td/Ts)$ (6)

$K_3 = K_cTd/Ts$ (7)

Where: Ts - sampling period; Kc - proportional amplification; Ti - integral time; Td - derivative time; Kd - differential magnification.

A flowchart of the defrothing control is shown in Fig. 5. With the alternate connection of the high and low potentials, when the fermentation broth gets in touch with the low potential, the low potential electrode is then turned ON. If there are more foams, the high and low potential electrodes are dipped into the fermentation broth, they will be activated simultaneously. The main interface for the computer supervision system includes setting, view, debug, soft measurement and fuzzy monitor. Due to the non-linearity, time-dependent nature and uncertainties of industrial ethanol fermentation, the conventional control algorithms cannot achieve the required effect precisely. For this purpose, a fuzzy control algorithm is added in the design. In Fig. 6, the fuzzy control (Fuzzy) and conventional control (PID) response curves are analoged. It can be found that the fuzzy control algorithm has better control effect than the conventional one.

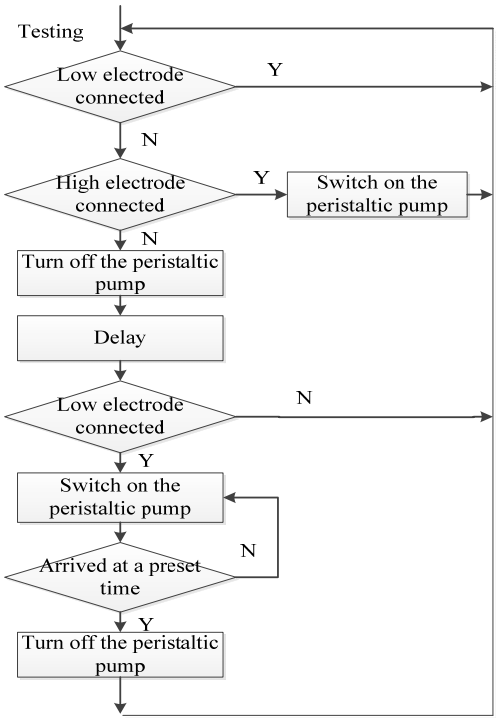

Figure 5: Flow chart of defoaming control

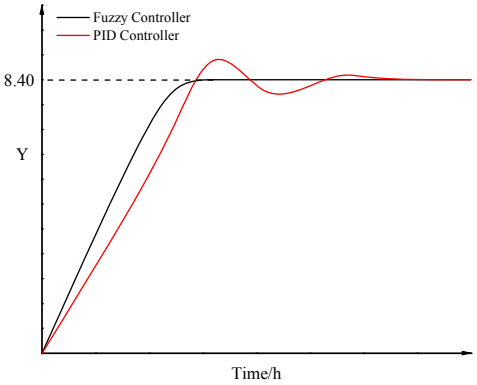

Figure 6: Comparison of fuzzy control and PID control response curves

4. Industrial ethanol fermentation under computer monitoring control

4.1 Change and the best control point of oxidation-reduction potential during fermentation

In the industrial ethanol fermentation process, the electron gain and loss in the solution reflects the metabolic capacity of the microorganism, as a key indicator for characterizing biochemical reactions during the ethanol fermentation. The high concentration in the ethanol fermentation environment will make the dissolved oxygen insufficient, the fermentation retards, and dopant with the byproducts. In this laboratory experiment, fermenter is equipped with a sterilized ORP electrode, and the LabView, a computer control software, used to acquire data. The biomass can be obtained by measuring turbidity, and then the dry biomass will be calculated using a standard curve for dry weight of biomass as a function of turbidity. We record the fermentation process from the change of the redox potential curve: there are the redox potential reduction, control activation and deactivation phases. The number and activity of yeast cells during industrial ethanol fermentation are critical to the fermentation process, and much more biomass can accelerate ethanol production efficiency. As shown in Fig. 7, the concentrations of viable bacteria in the ethanol fermentation process under the test of computer are compared. It can be seen that the concentrations of active bacteria at the early stage is almost constant. With the activation of the redox potential, the concentrations of viable bacteria under different controls show a significant disparity. That redox control system with a good concentration of viable bacteria has a better fermentation effect.

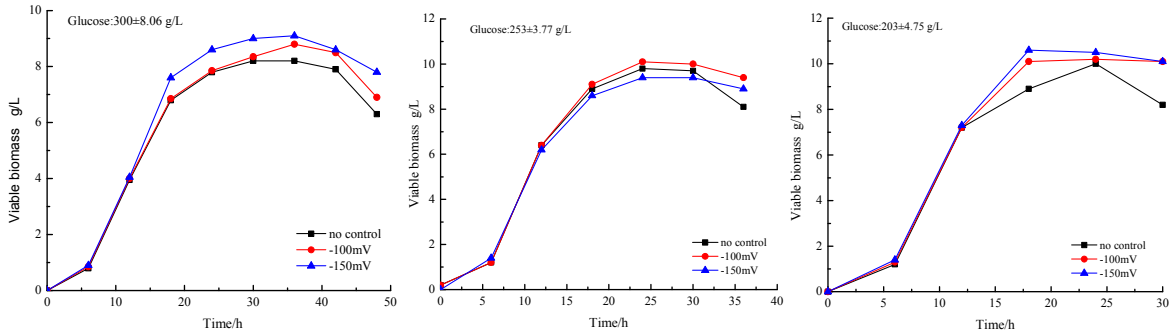

Figure 7: Viable biomass profiles under different glucose feeds and ORP controls

4.2 Ethanol fermentation dynamics under computer supervisory control

The role of substrates in industrial ethanol fermentation process cannot be ignored. High substrate and active bacteria concentrations can lead to a slow cell growth. The relationship between biomass and substrate can be calculated by the Monod equation, as shown in Eq. 8:

$$\mu=\mu_{max}\frac{S}{S+K_S} \tag{8}$$

Where, μ is the specific growth rate; μmax is the maximum specific growth rate; S is the substrate concentration; Ks is the half-saturated substrate concentration.

In the ethanol fermentation process, the formation amount of ethanol will also inhibit the fermentation with an effect as shown in Eq. 9:

$$\mu=\mu_0\left(1-\frac{P}{P_{max}}\right)^{\alpha} \tag{9}$$

Where, μ0 is the specific growth rate without ethanol; Pmax is the maximum ethanol tolerance concentration; α is the correction factor.

The complete growth dynamics model is shown in Eq. 10:

$$\mu=\mu max\frac{S}{S+K_S+S^2/K_I}\left(1-\frac{P}{P_{max}}\right)^{\alpha} \tag{10}$$

5. Conclusions

In this paper, the industrial ethanol fermentation is aimed to explore its process factors and fermentation dynamics with the help of computer technologies. The specific conclusions are derived as follows:

(1). The hardware equipment of ethanol fermentation control system includes four parts: pH meter, DOM, PLC slave computer and hardware circuit; the software include host computer data storage and treatment part and slave computer field data harvester and loop controller.

（2). There is a critical dissolved oxygen, super critical dissolved oxygen, the respiratory intensity will remain unchanged, but the critical concentration of dissolved oxygen varies greatly during each fermentation period, so that the critical concentration cannot be characterized with a given dissolved oxygen value.

(3). The quantity and activity of yeast cells in the industrial ethanol fermentation process are very key to the fermentation process. The more the biomass, the higher the production efficiency of ethanol; beyond that, the role of substrates and the ethanol formation amount cannot be ignored.

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