CHEMICAL ENGINEERING TRANSACTIONS
VOL. 71, 2018
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet
Guest Editors: Xiantang Zhang, Songrong Qian, Jianmin Xu

ISBN 978-88-95608-68-6; **ISSN** 2283-9216
DOI: 10.3303/CET1871069

Application of Computer Monitoring Technology in Industrial Ethanol Production and Fermentation

Pei Wang, Huan Tong, Huiying Shao

Information Engineering Department, Xingtai Polytechnic College, Xingtai 054000, China
wang_396@163.com

Factors that influence the industrial ethanol fermentation process are complex. The development of computer monitoring technology can optimize fermentation conditions to obtain the maximum yield. This paper discusses the application of computer control technology in industrial ethanol production and fermentation, and studies the dynamics of ethanol fermentation. It finds that the monitoring system includes hardware and software. Under the computer control, the system can automatically complete the environment control of fermenter without human intervention, acquire and process field data, greatly increasing the yield of ethanol fermentation. The number and activity of yeast cells, the function of substrate and the production of ethanol are very important in the fermentation process.

1. Introduction

The fermentation industry with a long history has become the basis of bioengineering and biochemical engineering. In recent decades, the ethanol fermentation industry has been developing increasingly and prospering (Haringa et al., 2018). Especially in the new biochemical engineering field, industrial ethanol fermentation has attracted more and more attention from the scientific, industrial and government sectors (Palacios-Bereche et al., 2014; Halder et al., 2016). For the large fermentation system, the improper operation may cause significant economic losses. Therefore, the parameter measurement, operation monitoring, automatic control, optimize operation and control of industrial ethanol fermentation process become key problems of optimization management and automation in the biochemical reaction process (Ashok and Kumar, 2017). Moreover, the rapid development of computer technology provides advanced automation tools for measuring, analyzing and controlling biochemical engineering (Sansonetti et al., 2011; Ho et al., 2016). The computer control technology, which is adopted to conduct real-time automatic control, management and optimization, can solve the instability, low fermentation coefficient, low energy consumption and high cost problems of ethanol fermentation process (Guan, 2015; Skupin and Metzger, 2017).
The environmental control of industrial ethanol fermentation process is of vital importance, including fermentation temperature, PH value, dissolved oxygen concentration control, defoaming control, feeding control, etc. (Cai et al., 2014). The industrial ethanol production and fermentation process is optimized and controlled by the computer's storage and tell computing capacity (Ranjbar et al., 2013). Industrial ethanol fermentation is a biochemical reaction process with complex mechanism. It is difficult to use the existing mathematical model to describe. The poor production experiment data repeatability brings many difficulties to mathematical modeling. The application of computer provides a great help for fermentation parameter measurement, data management and analysis, fermentation process optimization control (Zou et al., 2012). This paper studies the process of industrial ethanol fermentation with the help of computer technology, and develops a computer control system for the industrial ethanol fermentation process.

2. Control system design scheme

2.1 Fermentation process parameter measurement

It is necessary to accurately measure parameters to effectively operate and control the industrial ethanol production and fermentation process (Ahaotu et al., 2017; Guo et al., 2012). Fig. 1 shows the fermenter

Please cite this article as: Wang P., Tong H., Shao H., 2018, Application of computer monitoring technology in industrial ethanol production and fermentation, Chemical Engineering Transactions, 71, 409-414 DOI:10.3303/CET1871069

measuring system, including physical parameters (temperature, pressure, air flow, volume of fermented liquor, etc.), biological parameters (biomass concentration, metabolites concentration, substrate concentration, etc.), and chemical parameters (fermented liquid pH value and dissolved oxygen concentration). Among the parameters, temperature, fermented liquid pH value and dissolved oxygen concentration are the most important factors affecting the ethanol production and fermentation. Fig. 2 shows the microbial production curve for ethanol fermentation, which is divided into four periods, including retardation period, logarithmic period, stable period, and decaying period.

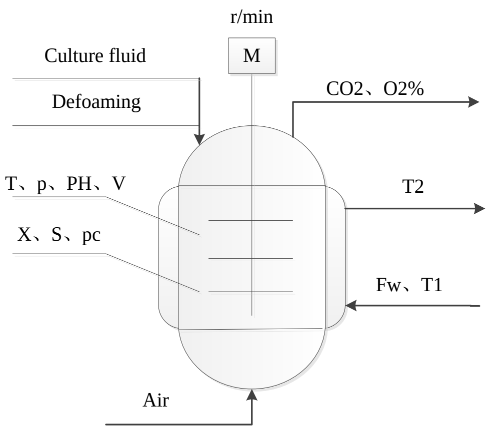

Figure 1: Fermenter measuring system

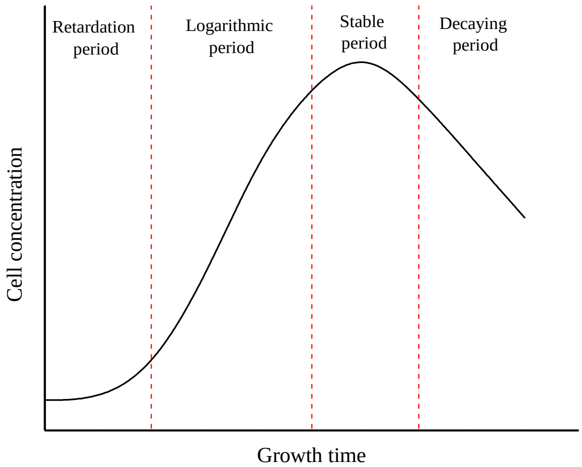

Figure 2: Microbial production curve for ethanol fermentation

2.2 Control system design scheme

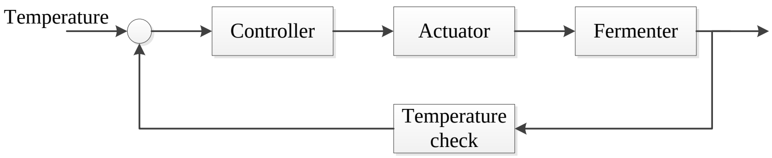

Figure 3: Temperature closed-loop control block diagram

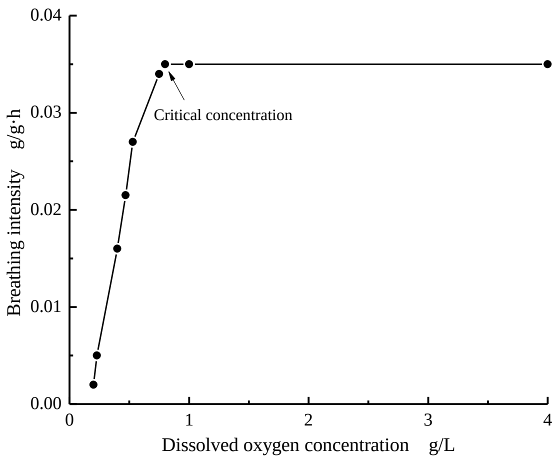

Figure 4: Relationship between respiratory intensity and dissolved oxygen concentration

In the large industrial ethanol fermentation process, the fermenter volume is large, generally from hundreds to thousands liters. The mechanical agitator is used to mix fermented liquid and air to raise the needed oxygen amount in the fermentation process (Li et al., 2011). Traditional fermenter control system consists of four control sections and four measurement sections. Four control sections (pH, temperature, defoaming and stirring speed control) adopt the closed-loop control mode (Mare š et al., 2016). Fig. 3 is the temperature closed-loop control block diagram. The controller sends a control signal through a given temperature, the actuator is used to heating or cooling in the fermenter, and the temperature check is conveyed to the controller, thus forming a closed-loop control circuit. Fig. 4 represents the relationship between respiratory intensity and dissolved oxygen concentration. After the dissolved oxygen concentration exceeds the critical concentration, the respiratory intensity still remains the same. But the critical oxygen concentration changes greatly at different fermentation periods. Therefore, a dissolved oxygen concentration cannot represent the critical concentration.

3. Ethanol production and fermentation control system design

3.1 Ethanol production and fermentation control system hardware design

The fermenter control system in this experiment uses PLC as the lower computer, which can collect, process and output various parameters. The hardware equipment of ethanol production and fermentation control system consists of pH meter, dissolved oxygen meter, PLC and hardware circuit. The PH meter adopts GKF high-temperature PH sensor system. The whole machine is small in size with less connection, which is convenient for debugging. The dissolved oxygen meter is a kind of multi-function meter integrating measurement and signal conversion. Different measurement units can be switched at any time, as well as the boundary, rate pulse width and rate pulse frequency control modes can be realized. The dissolved oxygen meter has the ability to store and backup data, to correct data and to ensure other information without being deleted after the power is out. PLC, as a programmable logic controller in the fermenter control system, can automatically control the fermenter. A sensor, a voltage or current source, and a zero signal are added to an input terminal.

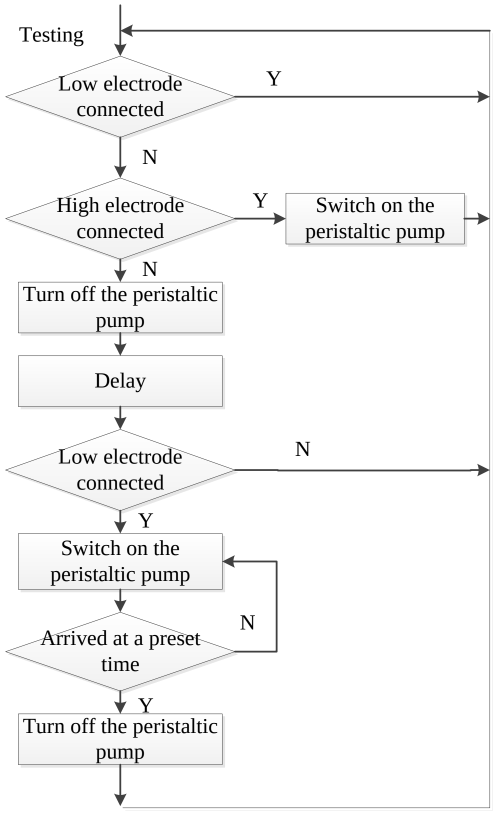

Figure 5: Flow chart of defoaming control

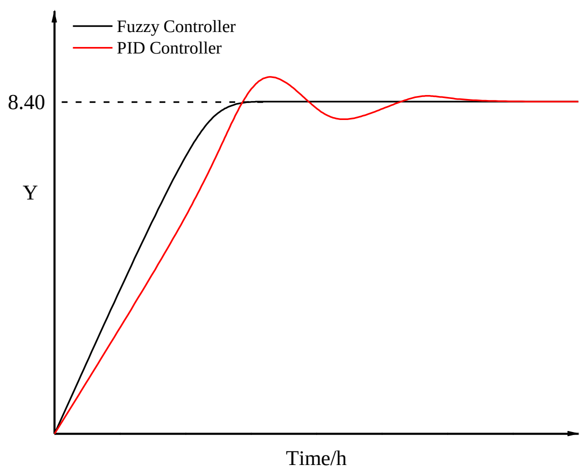

Figure 6: Comparison of fuzzy control and pid control response curves

3.2 Ethanol production and fermentation control system software design

The software design of computer control system is divided into upper-computer data storage and processing part as well as lower-computer field data acquisition and loop control part. The PLC is directly connected with the test device, and the temperature, pH value, dissolved oxygen and other data are recycled and reciprocated to measure. The upper computer and the lower computer are directly connected to conduct real-time data collection and monitoring. In the process of industrial ethanol production and fermentation, the temperature control system is required to track the change of a given value quickly, with little overshoot and no residual difference. The control algorithm is shown in equations 1 and 2:

$$\Delta U_k=K_I E_K-KcE_{K-1}+\Delta UD_K \tag{1}$$

$$\Delta UD_K=\alpha\cdot\Delta UD_{K-1}+(1-\alpha)(K_1E_K-K_2E_K+K_3E_{K-2}) \tag{2}$$

$$\Delta U_k=U_k-U_{k-1} \tag{3}$$

$$K_I=K_c(1+Ts/Ti) \tag{4}$$

$$K_1=K_c(1+Td/Ts) \tag{5}$$

$$K_2=K_c(1+2Td/Ts) \tag{6}$$

$$K_3=K_cTd/Ts \tag{7}$$

where Ts is the sampling period, Kc the proportional magnification, Ti the integration time, Td the differential time, and Kd the differential magnification.

The flow chart of defoaming control is shown in Fig. 5. Low and high potential connected is carried out. When the fermented liquid contacts with the low potential, the low electrode is connected. The foaming makes the high electrode in contact with the fermented liquid. The high and low potentials will be connected at the same time. The computer’s main monitoring interface includes setting, viewing, system debugging, soft measurement and fuzzy monitor. Because of the nonlinearity, variability and uncertainty of industrial ethanol fermentation, conventional control methods cannot accurately achieve the desired effect. Fuzzy control algorithm is added in the computer design. Fig. 6 shows the comparison of fuzzy control and PID control response curves, which expresses that the control effect of fuzzy control algorithm is better than that of PID control algorithm.

4. Industrial ethanol fermentation under computer monitoring and control

4.1 ORP changes and optimal control points during fermentation

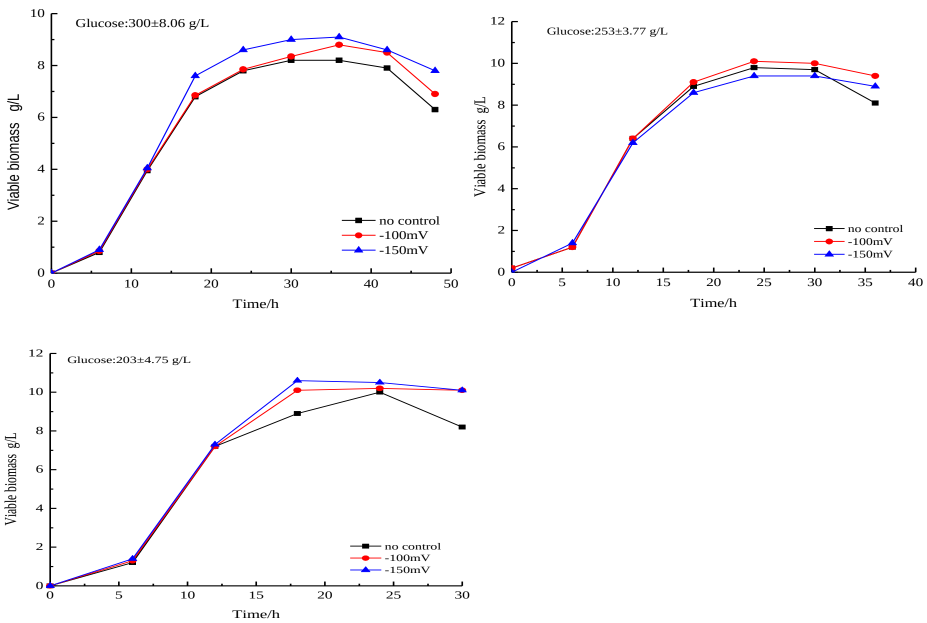

Figure 7: Viable biomass profiles under different glucose feeds and ORP controls

In the process of industrial ethanol fermentation, the ability of electron gain and loss in solution reflects the metabolic capacity of microorganisms, which is an important index of biochemical reaction in the ethanol fermentation process. If the ethanol concentration in the fermentation environment is high, it will lead to insufficient dissolved oxygen, decreased fermentation rate and increased by-products. This experiment provides the ORP electrode for the fermenter to sterilize, and use the computer control software LabView to collect data. Biomass is obtained by measuring the turbidity. The standard curve of turbidity and biomass dry weight is used to calculate the biomass dry weight. The fermentation process is recorded based on ORP changes, including ORP lower stage, ORP control start stage and ORP control end stage. The number and activity of yeast cells in industrial ethanol fermentation are very important to the fermentation process, and the increase of biomass can accelerate the production efficiency of ethanol. Fig. 7 is the viable bacteria concentration contrast in the ethanol fermentation under the computer detection, which shows the initial viable bacteria concentration is nearly the same. With the opening of ORP, the viable bacteria concentration under different control shows significant differences. The ORP control system with a better viable bacteria concentration possesses better fermentation effects.

4.2 Ethanol fermentation dynamics under computer monitoring and control

The role of substrate in industrial ethanol fermentation cannot be ignored. High substrate concentration and active bacteria concentration will slow the cell growth. The relationship between biomass and substrate is expressed in Monod, as shown in equation 8:

$$\mu=\mu_{max}\frac{S}{S+K_S} \qquad (8)$$

, where μ is the growth rate, μ_{max} the maximum growth rate, S the substrate concentration, and Ks the half-saturated substrate concentration.
In the ethanol fermentation process, the amount of ethanol production also inhibits the fermentation process, as shown in equation 9:

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

, where, μ_0 is the growth rate without ethanol, Pmax the maximum ethanol tolerance concentration, and α the correction factor.
The complete growth dynamics model is shown in equation 10:

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

5. Conclusions

This paper studies the industrial ethanol fermentation and production process with the help of computer technology, and the dynamics of ethanol fermentation under computer monitoring. The conclusions are as follows:

(1) The hardware equipment of ethanol production and fermentation control system consists of pH meter, dissolved oxygen meter, PLC and hardware circuit. The software design of computer control system is divided into upper-computer data storage and processing part as well as lower-computer field data acquisition and loop control part.

(2) After the dissolved oxygen concentration exceeds the critical concentration, the respiratory intensity still remains the same. But the critical oxygen concentration changes greatly at different fermentation periods. Therefore, a dissolved oxygen concentration cannot represent the critical concentration.

(3) The number and activity of yeast cells in industrial ethanol fermentation are very important to the fermentation process, and the increase of biomass can accelerate the production efficiency of ethanol. In addition, the effects of substrate and ethanol production in industrial ethanol fermentation cannot be ignored.

References

Ahaotu N.N., Anyogu A., Obioha P., Aririatu L., Ibekwe V.I., Oranusi S., 2017, Influence of Soy Fortification on Microbial Diversity During Cassava Fermentation and Subsequent Physicochemical Characteristics of Garri, Food Microbiology, 66, 165-172, DOI: 10.1016/j.fm.2017.04.019

Ashok A., Kumar D.S., 2017, Different Methodologies for Sustainability of Optimization Techniques used in Submerged and Solid State Fermentation, Biotech, 7(5), 1-12, DOI: 10.1007/s13205-017-0934-z

Cai J., Zhu B.Q., Wang Y.H., Lu L., Lan Y.B., Reeves M.J., 2014, Influence of Pre-fermentation Cold Maceration Treatment on Aroma Compounds of Cabernet Sauvignon Wines Fermented in Different Industrial Scale Fermenters, Food Chemistry, 154(2), 217-229, DOI: 10.1016/j.foodchem.2014.01.003

Guan S., 2015, Modeling and Optimization of the Glutamic Acid Fermentation Process Using Computational Intelligence Techniques, Neurocomputing, 169, 403-411, DOI: 10.1016/j.neucom.2014.10.094

Guo W.L., Du Y.P., Zhou Y.C., Yang S., Lu J.H., Zhao H.Y., 2012, At-line Monitoring of Key Parameters of Nisin Fermentation by Near Infrared Spectroscopy, Chemometric Modeling and Model Improvement, World Journal of Microbiology & Biotechnology, 28(3), 993-1002, DOI: 10.1007/s11274-011-0897-x

Halder G., Dhawane S.H., Dutta D., Dey S., Banerjee S., Mukherjee S., 2016, Computational Simulation and Statistical Analysis of Bioethanol Production from Madhuca Indica, by Batch Fermentation Process Using Saccharomycescerevisiae, Sustainable Energy Technologies & Assessments, 18, 16-33, DOI: 10.1016/j.seta.2016.09.004

Haringa C., Tang W., Wang G., Deshmukh A.T., Winden W.A.V., Chu J., 2018, Computational Fluid Dynamics Simulation of an Industrial P. Chrysogenum, Fermentation with a Coupled 9-pool Metabolic Model: Towards Rational Scale-down and Design Optimization, Chemical Engineering Science, 175, 12-24, DOI: 10.1016/j.ces.2017.09.020

Ho Q.T., Verboven P., Ambaw A., Verlinden B.E., Nicolaï B.M., 2016, Transport Properties of Fermentation Metabolites Inside ‘Conference’ Pear Fruit, Postharvest Biology & Technology, 117, 38-48, DOI: 10.1016/j.postharvbio.2016.01.008

Li D., Qian L., Jin Q., Tan T., 2011, Reinforcement Learning Control with Adaptive Gain for a Saccharomyces Cerevisiae Fermentation Process, Applied Soft Computing, 11(8), 4488-4495, DOI: 10.1016/j.asoc.2011.08.022

Mareš J., Kukal J., Hrnčiřík P., Náhlík J., 2016, Process State Classification of Fed-batch Fermentation Based on Process Variables Analysis, Biochemical Engineering Journal, 112, 178-185, DOI: 10.1016/j.bej.2016.04.019

Palacios-Bereche R., Ensinas A., Modesto M., Nebra S.A., 2014, New Alternatives for the Fermentation Process in the Ethanol Production from Sugarcane: Extractive and Low Temperature Fermentation, Energy, 70(3), 595-604, DOI: 10.1016/j.energy.2014.04.032

Ranjbar M., Shirazian S., Ghafarnejad Parto S., Ahmadi M., 2013, Computational Fluid Dynamics Simulation of Mass Transfer in the Separation of Fermentation Products Using Nanoporous Membranes, Chemical Engineering & Technology, 36(5), 728-732, DOI: 10.1002/ceat.201300008

Sansonetti S., Hobley T.J., Calabrò V., Villadsen J., Sin G., 2011, A biochemically Structured Model for Ethanol Fermentation by Kluyveromyces Marxianus: A Batch Fermentation and Kinetic Study, Bioresource Technology, 102(16), 7513-7520, DOI: 10.1016/j.biortech.2011.05.014

Skupin P., Metzger M., 2017, Stability Analysis of the Continuous Ethanol Fermentation Process with a Delayed Product Inhibition, Applied Mathematical Modelling, 49, 48-58, DOI: 10.1016/j.apm.2017.04.025

Zou X., Xia J.Y., Chu J., Zhuang Y.P., Zhang S.L., 2012, Real-time Fluid Dynamics Investigation and Physiological Response for Erythromycin Fermentation Scale-up from 50 l to 132 m (3) Fermenter, Bioprocess & Biosystems Engineering, 35(5), 789-800, DOI: 10.1007/s00449-011-0659-z