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Environmental parameter control method and system design of intelligent Daqu fermentation room

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Abstract

As the manufacturing industry develops towards digitalization, informatization and intelligence, various smart devices are used in manufacturing. In response to the current problems in the fermentation process of Daqu in Luzhou-flavor wineries: manual turning of Daqu, labor intensive and harsh environment for turning Daqu, unable to obtain the process parameters in the Daqu fermentation room in real time, resulting in workers' environmental regulation in the Daqu fermentation room Not waiting for a series of problems in time, this paper proposes an intelligent Daqu fermentation room control system, which can monitor the fermentation temperature and humidity of Daqu in the Daqu fermentation room in real time, and realize paperless records. At the same time, the environment in the Daqu fermentation room is adjusted in time according to the obtained process parameters.

Keywords

Daqu fermentation room; environment and temperature and humidity monitoring; temperature and humidity intelligent control; system design.

1. Introduction

For winemaking, "qu is the bone of wine" is the essence of traditional brewing, which shows that Daqu fermentation occupies a very high position in the winemaking process. The traditional Daqu fermentation room is a rectangular parallelepiped made of red brick and cement walls, with a layer of straw on the top and a certain thickness of rice husk on the ground. In the Daqu fermentation process, it is necessary to cover the entire Daqu pile with straw mats. During the fermentation process of Daqu, the control of technological parameters is quite complicated, and the main control objects are the temperature and moisture of Daqu. According to the fermentation situation of Daqu, the workers implement the turning process and open windows to adjust the temperature and humidity of Daqu. Since the current method of measuring temperature and humidity in Daqu is mainly to periodically read the temperature and humidity in the Daqu fermentation room, workers can only read the temperature and humidity at the moment when reading, and cannot reflect the recent temperature and humidity changes, which may cause Mistakes in manual control, or untimely control results in unstable quality of Daqu. At the same time, the temperature and humidity data measured by the workers in the Daqu fermentation room need to be recorded on paper in a form. It is cumbersome to organize the temperature and humidity data later, and it is not convenient to optimize the Daqu fermentation process. Therefore, the automation, intelligent control, environmental monitoring and data visualization of the traditional Daqu fermentation room have become particularly important.

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2. Design of intelligent control system for Daqu fermentation room

2.1. Daqu fermentation room temperature and humidity control strategy and data processing strategy

1) Daqu fermentation room data control strategy

The Daqu fermentation room in this paper is a skid-mounted Daqu fermentation room experimental platform. The three-dimensional space of the platform is consistent with the three-dimensional space of the winery. The fermentation process and process parameters of Daqu are all produced by a winery that produces Luzhou-flavor liquor in Yibin. provide. The winery provides five sets of temperature and humidity curves with better fermentation quality for Daqu, as shown in the figure below.

It can be seen from the fermentation temperature curve of Daqu that the overall curve trend of Daqu fermentation temperature in the five koji chambers is consistent. As the fermentation progresses, the temperature of Daqu's fermentation rapidly rises to about 55°C within 0-5 days of the initial stage of fermentation, and then the temperature of Daqu fermentation is maintained at about 55°C during the medium period of 5-16 days. After 16-25 days, the fermentation temperature is maintained. Slowly decrease to the same room temperature as the outside, and then after 25 days, the temperature of the Daqu fermentation room basically remains unchanged at about 30°C. During the initial stage of fermentation in Daqu fermentation, the humidity rises rapidly to about 60°C within 0-5 days. During the next 5-16 days, the humidity in Daqu fermentation is maintained at about 80% RH, and then slowly decreases. After 16-32 days, the fermentation humidity continues to slowly decrease to 7%. RH means in a dry state.

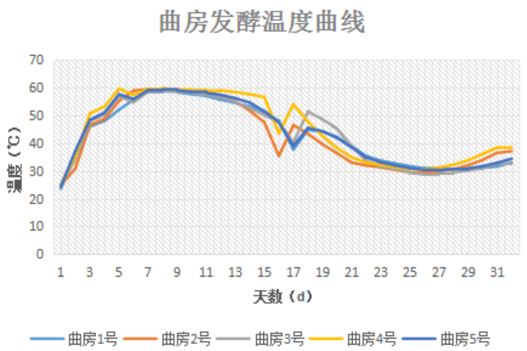


Figure 1-1 The humidity curve of Daqu fermentation

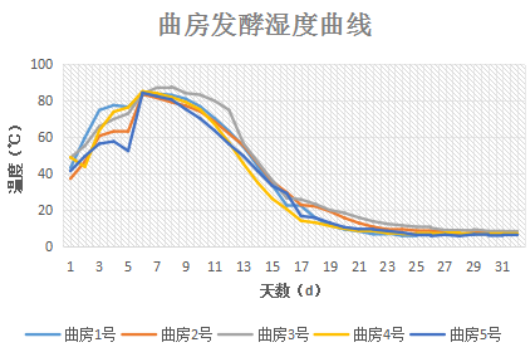
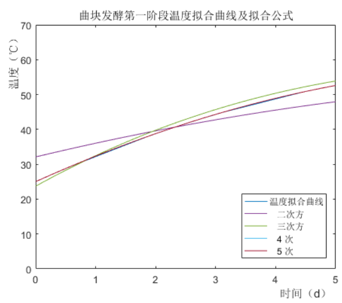
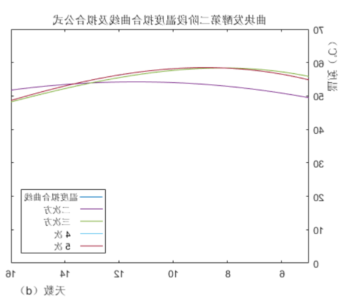


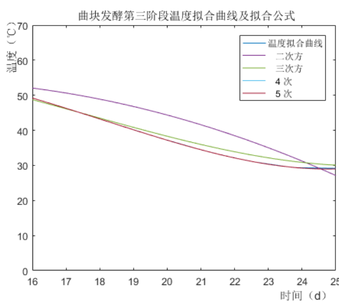
Figure 1-2 The humidity curve of Daqu fermentation



(a) The first stage fitting curve



(b) The second stage fitting curve



(c) The third stage fitting curve

Fig. 1-3 Segment fitting curve of Daqu fermentation temperature

According to the Daqu fermentation room technology: the whole fermentation process is divided into three stages, namely the low-temperature culture zone, the high-temperature

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transformation zone, and the moist and fragrance-producing period in the back fire row. There is a Daqu turning process between each two stages, and the temperature difference after turning is large, so the Daqu fermentation temperature is divided into three stages to fit separately. The fitted curve and function are shown in the figure below.

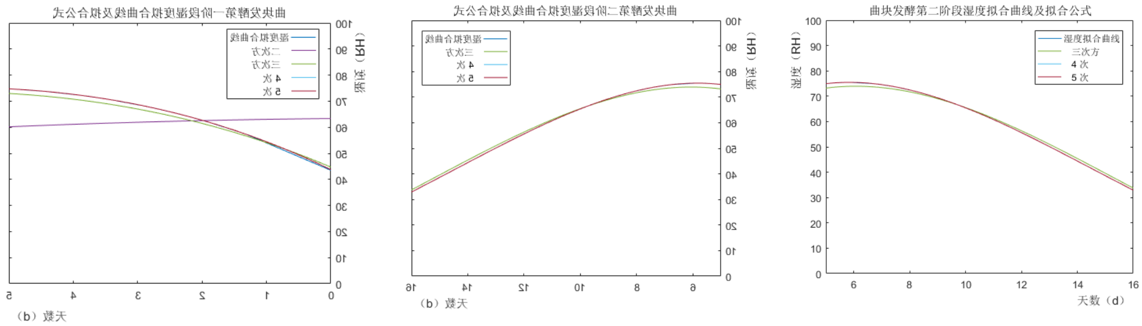
It can be seen from the above figure that the temperature segmentation function of Daqu fermentation room is obtained according to the fitted curve as follows.

$$y=\begin{cases}0.00049x^4-0.0071x^3-0.42x^2+7.8x+25 & (0\le x\le 5)\\ 0.00018x^4-0.0016x^3-0.28x^2+4.7x+38 & (5<x\le 16)\\ 0.00038x^4-0.0073x^3-0.36x^2+8x+18 & (16<x\le 25)\end{cases} \quad (1\text{-}1)$$

Formula: x represents the number of days (d)

y represents temperature (℃)

In the same way, the humidity curve and function of Daqu fermentation are as follows.



(a) Fitting curve in the first stage (b) Fitting curve in the second stage (c) Fitting curve in the third stage

Figure 1-4 Segmented fitting curve of Daqu fermentation temperature

It can be seen from the above figure that the section function of Daqu temperature is obtained according to the fitted curve as shown in the table below.

$$y=\begin{cases}-0.00029x^4+0.04x^3-1.4x^2+12x+44 & (0\le x\le 5)\\ -0.00028x^4+0.039x^3-1.3x^2+12x+44 & (5<x\le 16)\\ -0.00017x^4+0.024x^3-0.84x^2+6x+18 & (16<x\le 25)\end{cases} \quad (1\text{-}2)$$

Formula: x represents the number of days (d)

y represents temperature (℃)

2) Data processing strategy of Daqu fermentation room

In the traditional Daqu fermentation room, there is only one sensor for detecting temperature and humidity, which cannot reflect the accuracy of measuring the temperature and humidity of Daqu. According to the principle of arranging the monitoring points in a rectangular plane, there are 5 monitoring points on each floor of Daqu in this paper. Diagonal distribution, Daqu has three layers. The temperature and humidity data collected by 15 Daqu temperature and humidity sensors are respectively summed and the average of the current temperature and humidity is calculated, and the calculated average is used as the current temperature and humidity of Daqu. The specific formula is shown below.

$$Z=\sum_{i=1}^{n} a_i\ /15 \quad (i=1,2,3\dots .n) \qquad (1\text{-}3)$$

Formula: Z represents the average number of measured values of all Daqu temperature and humidity sensors

a_i represents the number of measured values

2.2. Realization of intelligent control algorithm

Because the temperature and humidity control of Daqu fermentation room has hysteresis and nonlinear characteristics, it is necessary to use fuzzy PID control algorithm to control temperature and humidity. This thesis is designed for the temperature control system of Daqu fermentation room. The error e between the actual temperature y of Daqu and the given temperature r and the rate of change of Daqu temperature error e_c are selected as the two input variables of the system. Δki, Δkp, Δkd are used as the output variables of the fuzzy controller, and used as the compensation of k_{p0}、 k_{i0}、 k_{d0} in the PID controller,

This paper uses the Mamdani fuzzy logic inference method to design a dual-output-three-input two-dimensional fuzzy inference adaptive PID controller, as shown in the figure below.

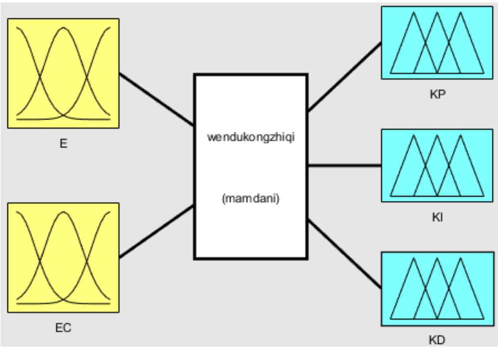


Figure 1-5 Fuzzy PID adaptive controller

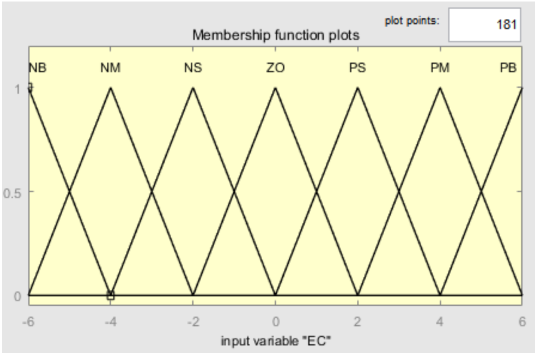


Figure 1-6 Membership function of the fuzzy controller

Table 1-1 Control rule table of the fuzzy controller

e \ e_c ΔKp/ΔKi/ΔKd	NB	NM	NS	ZO	PS	PM	PB
NB	PB/NB/PS	PB/NB/NS	PM/NM/NB	PM/NM/NB	PS/PS/NB	ZO/ZO/NM	ZO/ZO/PS
NM	PB/NB/PS	PB/NB/NS	PM/NM/NB	PS/NS/NM	PS/PS/NM	ZO/ZO/NS	NS/ZO/ZO
NS	PM/NB/ZO	PS/NM/NS	PM/NS/NM	PS/NS/NM	ZO/ZO/NS	NS/NS/NS	NS/PS/ZO
ZO	PM/NB/ZO	PM/NM/NS	PS/PS/NS	ZO/ZO/NS	NS/NS/NS	NM/PS/NS	NM/PM/ZO
PS	PS/NM/ZO	PS/NS/ZO	ZO/ZO/ZO	NS/NS/ZO	NS/PS/ZO	NM/PM/ZO	NM/PB/ZO
PM	PS/ZO/PB	ZO/ZO/NS	NS/PS/PS	NM/PS/PS	NM/PM/PS	NM/PB/PS	NB/PB/PB
PB	ZO/ZO/PB	ZO/ZO/PM	NM/PS/PM	NM/PM/PM	NM/PM/PS	NB/PB/PS	NB/PB/PB

Auto-tuning e and e_c at different times through PID. At the same time, the range of input and output is defined as the domain of the fuzzy set: [-6, 6], fuzzy subsets e_c, e, Δki, Δkp, Δkd are all: {NB (negative large), NM (negative medium)), NS (negative small), ZO (zero), PS (positive small), PM (positive middle), PB (positive large)}; the F subset is equally divided into 7 levels by using the triangular membership function, among which the fuzzy controller of e_c The membership function of is shown in Figure 1-6.

According to the adjustment characteristics of the three parameters in the traditional PID, expert knowledge and human control experience, the rule table of the fuzzy controller is summarized. The rule table is shown in the following table.

This paper uses the Siemens 200Smart controller, and the programming software is Step7. It is difficult to use the internal instructions of the Step7 software to write rules. The debugging and modification process of fuzzy rules is very time-consuming. Therefore, this paper adopts the method of offline calculation of the lookup table. The Fuzzy Logic Designer tool in Matlab2016 software obtains the lookup table.

The fuzzy control table of the three output parameters of the fuzzy self-tuning PID controller is calculated offline in advance through the FIS tool in the Matlab software, and is called at any time in the control program as a subroutine. In real-time control, the deviation and deviation change rate values are obtained in a certain sampling period, and after they are discretized, the corresponding fuzzy control table is queried to obtain the discrete value of PID parameter correction value, and then these discrete values are processed through precision to obtain the The correction values of the cycle PID parameters Δkp, Δki and Δkd, and finally add the initial value to obtain the three control parameters of the cycle PID control.

The fuzzy control table has 7 rows and 7 columns and a total of 49 elements. For the convenience of calculation and table lookup, the domain of discourse is transformed into the domain of positive numbers, that is, the domain of [-3, +3] is transformed into the domain of [0, +6], and the domains of deviation, deviation change rate and control quantity are obtained respectively. For: e = [0, +6], e_c = [0, +6], Δkp, Δki and Δkd = [0, +6], select the continuous storage area in PLC, such as [DM0000, DM0048], a total of 49 storage units. Each storage unit corresponds to a table bit, which is filled in from left to right and top to next. Then there is the following relationship between the deviation e and the deviation change rate e_c and the number of the digital storage unit: storage unit number = e + 7× e_c. Therefore, only e and e_c are required, and the storage unit number can be obtained by the above formula, and then the indirect addressing instruction can be used to find out the content of the storage unit, and multiply it by the scale factor to obtain Δkp, Δki and Δkd. And take Δkp, Δki and Δkd as the input of PID controller to control the output power of electric heater.

2.3. Hardware device control

Combined with the intelligent skid-mounted Daqu fermentation room researched in this paper, the Daqu fermentation process control can be divided into air internal circulation and air external circulation. The specific implementation control is shown in the following table.

Table 1-2 Hardware equipment control technology

Working condition	Cycle mode	Start the hardware device
The measured humidity is higher than the required humidity,	external circulation	start electric valve 1, 3, blower 4
The measured humidity is higher than the required humidity,		
The measured temperature is lower than the required temperature	Internal circulation	Start electric valve 2, blower 4, electric air heater 5
Measure the humidity is lower than the required humidity,		Start electric valve 2, 6, blower 4, ultrasonic humidifier 7

It can be seen from the above table that when the temperature and humidity measured by the Daqu temperature and humidity sensor are higher than the current temperature and humidity

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of the fermentation process, the electric valves 1, 3 and blower 4 will be activated as an external circulation method to remove the hot air inside the Daqu fermentation room. The air with high humidity is discharged to the outside of the Daqu fermentation room to reduce the temperature and humidity. When the temperature and humidity measured by the Daqu temperature and humidity sensors are lower than the temperature and humidity required by the current Daqu fermentation process, the valve 2 and the blower 4 are activated as the internal circulation mode. When the temperature is lower than the temperature required by the current Daqu fermentation process, the electric air heater is turned on to heat the air in the Daqu fermentation room. When the humidity is lower than the humidity required by the current Daqu fermentation process, turn on the ultrasonic humidifier to increase the humidity of the air in the Daqu fermentation room, thereby increasing the moisture of Daqu.

Using the Kunlun Tongtai touch screen, the skid-mounted Daqu fermentation room automatic control system was configured, and the configuration screen is shown in the figure below.

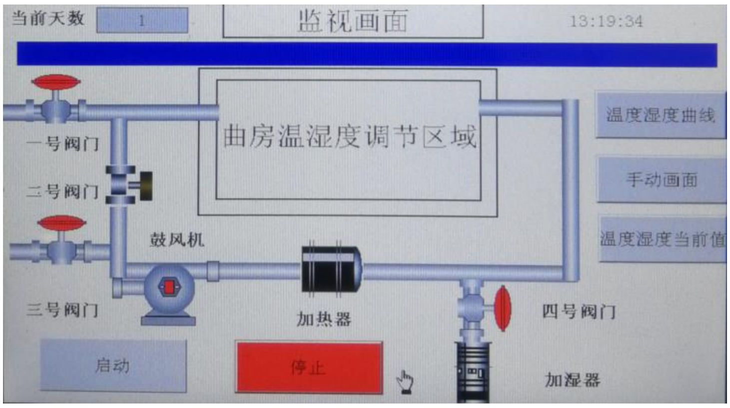

Figure 1-7 Automatic control interface of skid-mounted Daqu fermentation room

As can be seen from the above figure, click the start button, the Daqu fermentation room automatic control system is turned on, and the PLC processes and calculates through the internal program of the PLC according to the data transmitted by the sensor, and compares the calculated results with the current time Daqu fermentation temperature and humidity values. And according to the values obtained from the comparison, the start and stop of valves, blowers, heaters and other equipment are controlled, so as to realize automatic control of Daqu temperature and humidity process parameters.

3. Monitoring system design of Daqu fermentation room

According to the skid-mounted Daqu fermentation room fermentation platform, there are 16 monitoring points in the whole koji room. Among them, a monitoring point is set on the top of the Daqu fermentation room as the temperature and humidity detection of the air in the whole Daqu fermentation room (except the monitoring points inside the koji pile), and the remaining 15 There are five monitoring points in each layer, arranged in a diagonal rectangle, and there are three layers in total. The detection rectangles of the monitoring points on each layer are at the same position, so the detection points for the entire curved pile are shown in the figure below.

In this paper, a wired temperature and humidity sensor is used. According to the temperature and humidity data collection and real-time display requirements of the Daqu fermentation room, a Daqu temperature and humidity monitoring system is designed. The wiring diagram of Daqu temperature and humidity monitoring system equipment is shown below (the figure only shows the wiring diagram of a temperature and humidity sensor)

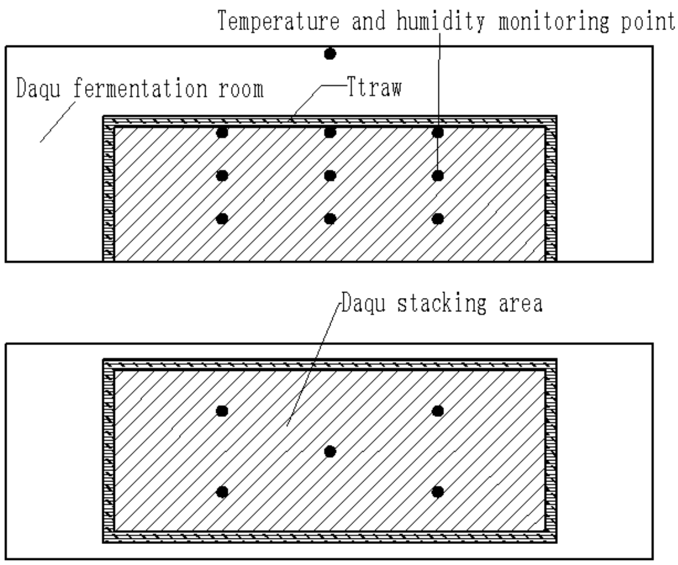

Figure 2-1 Layout of monitoring points in the curved room

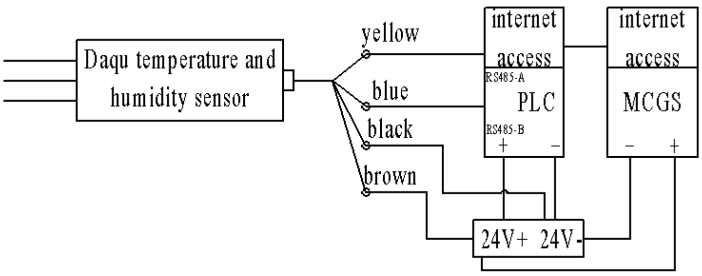

Figure 2-2 Wiring diagram of temperature and humidity sensor data collection and real-time display

Figure 2-3 Daqu fermentation room temperature and humidity current value display interface

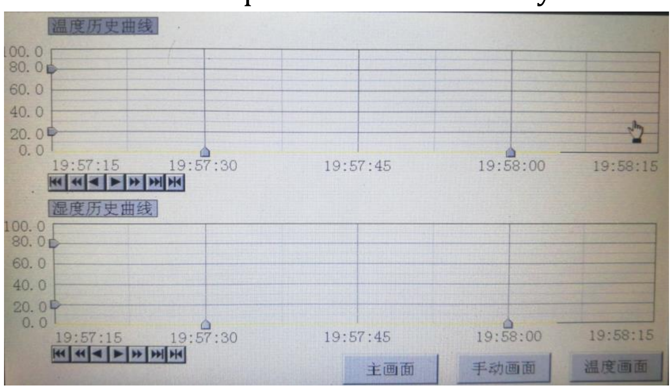

Figure 2-4 Temperature and humidity curve configuration interface

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The data collected by the temperature and humidity sensor is transmitted to the Kunlun Tongtai touch screen through the temperature and humidity reading and writing instructions inside the PLC, and the current value measured by the temperature and humidity sensor is displayed in real time through the touch screen configuration, and the current value of the temperature and humidity in the Daqu fermentation room The display interface is shown in the figure below.

The operator needs to check the temperature and humidity of the koji in the Daqu fermentation room in order to implement the corresponding process control, so they need to know the current and recent temperature and humidity of the koji fermentation. Through the configuration of the Kunlun Tongtai interface, you can know the temperature, humidity and historical curve change trend of the recent Daqu fermentation, so as to better implement the corresponding process control for Daqu fermentation. The temperature and humidity curve configuration interface is shown in the figure below.

4. Concluding

On the basis of the skid-mounted music room based on the traditional music room, an intelligent music room control system is designed. This system can well solve the current problems in the traditional music room and realize the automatic temperature and humidity control of the music room at the same time. Real-time monitoring of the temperature and humidity parameters of the music room and realize paperless recording. The fuzzy algorithm makes the control effect of temperature and humidity more stable and faster.

References

[1] Sun Li, Sun Shunyuan. Design and application of low-power wireless temperature and humidity detection system for curved rooms[J]. Measurement and Control Technology, 2017, 36(05): 29-32.

[2] Meng Sidong, Tian Jianping, Zhang Liangdong, Hu Yong, Xie Liangliang. Design and research of hanging-turning robot[J]. Food Industry, 2016, 37(12): 194-197.

[3] Zhang Xia, Qiao Zongwei, Lei Xuejun. Study on the effect of manual turning on the consistency of physicochemical indexes of fermented koji[J]. Winemaking Technology, 2018(10):59-64.

[4] Wang Zhikai, Guo Zongren, Li Yan. Two programming methods to realize fuzzy control with PLC [J]. Industrial Control Computer, 2002(02): 61-62+33.

[5] Wei Qingzhi, Li Zhengming, Sun Jun. Boiler superheated steam temperature control system based on fuzzy adaptive PID control[J]. Mechanical Design and Manufacturing, 2010(07): 173-175.

[6] Zheng Wen, Zhang Yunbo. PLC-based fuzzy adaptive PID control of boiler liquid level[J]. Bulletin of Science and Technology, 2013, 29(11): 85-88+122.

[7] Gong Yulin. A reactor temperature control system based on fuzzy PID adaptive tuning parameters [J]. Journal of Dongguan University of Technology, 2021, 28(01): 102-106.

[8] Wu Jianwei, Tang Lixin. Design and simulation of fuzzy adaptive PID control for temperature control system[J]. Journal of Hefei Normal University, 2012, 30(06): 35-37.