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The pH value control of clarifying process in sugar refinery based on fuzzy control[1]

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Abstract. With the continuous development of automation technology, the application of the technology has also penetrated into the sugar industry. In this paper, the research status of pH control in sugar factory was analyzed, and the development and application of fuzzy control were illustrated. On the basis of fuzzy adaptive PID control, pH intelligent control system and software and hardware were designed, and the experimental results were analyzed. The experimental results show that the pH intelligent control system can effectively guarantee the stability of pH value in the clarifying process of sugar refinery, and it also has better control effect on temperature. In addition, the feasibility of fuzzy control can be ensured, which will contribute to the application research of pH value control in the clarifying process of sugar factory based on fuzzy control.

Key words. Automation technology, sugar industry, fuzzy control, pH value.

1. Introduction

Since the late 1950s, with the development of a large number of engineering practices, especially the development of space technology, the automation control theory has been developed vigorously. Because of the wide application of automation technology in many fields such as industrial production, electric power, traffic, iron and steel, the production efficiency of various industries has been improved, and the economic benefits have been greatly improved. More and more people believe that the level of automation of an enterprise has become an important indicator of the competitiveness of the entire enterprise market.

In recent years, automation technology has been gradually introduced into the sugar industry. At present, most sugar mills in our country adopt the clarification process of sulfurous acid method. Only a small part of sugar factories adopt carbonate clarification process. Because of the impurities removed by the carbonic acid

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method is more than that removed by the method of sulfuric acid, the clarification effect of carbonic acid method is better than many KIA sulfuric acid methods [1]. But the production cost of carbonate method is much higher than that of KIA sulfuric acid method. Especially in the production of equipment, the production facility that carbonate method requires is more than that of sulfuric acid method, and the whole process of production is also more complex. Therefore, in the existing technical level, many sugar enterprises choose sulfurous acid method. Subsequently, with the development of science and technology, especially the improvement of automation, the cost of production has been reduced, and the carbonic acid method has been widely used [2].

Whether it is carbonate or sulfurous acid method, the pH value in the clarifying process of the sugar refinery is an important index of the whole section, which is related to the effect of the whole clarification. Recognizing the importance of the pH value in the clarifying process of the sugar refinery, a large amount of research work has been done on the control of pH stability [3]. The lag and inertia link exist in the neutralization process of pH value in sugarcane juice. In 1991, Wu Minghua of South China University of Technology adopted the Dalin algorithm with parameter self-correction to design computer control system, which improved the quality of manual control. Aiming at the problems of neutralization pH value and pH value control of clarified juice, teachers and students of Guangxi University used the fuzzy control algorithm, adaptive dynamic programming and genetic algorithm to optimize the design of control system control, so as to improve the efficiency and accuracy of control [4]. But it was only in the theoretical simulation stage, and the real application was very rare. In the past, due to the relative backwardness of automation technology, there were few on-line inspection devices in the clarifying process of sugar refinery. Most of the detection parameters were adjusted by manual experience, which resulted in low quality sugar content in the finished sugar and low production efficiency of sugar mills [5]. With the development of economy and society, the demand for high quality sugar in domestic and foreign markets is increasing. How to improve the quality of sugar ratio has become a problem for sugar refinery enterprises. To promote the development of production automation in sugar factories has become the focus of research in the field of sugar production.

In the second part of this paper, the research status of pH control in sugar factories was analyzed and summarized, and the development and application of fuzzy control were illustrated. The third part used fuzzy adaptive PID control to design pH intelligent control system in the clarifying process of sugar refinery, and the hardware part and software parts were designed, respectively. In the fourth part, the pH value control and the temperature control performance of the control system were analyzed through the experiment, and its feasibility was studied. In the fifth part, the full text was summarized and the conclusions were drawn, which supported the research of pH value control in the clarifying process of sugar factory based on fuzzy control.

2. State of the art

2.1. Research status of pH control in sugar factory

The clarifying process of a sugar refinery is a complicated nonlinear and large delay link. Nonlinearity is that it is not a linear relation between the pH value of cane juice and the induction voltage of glass electrode. When the pH value is about 7, with the added acid or base, the pH value of sugarcane juice changes rapidly instead of following a certain linear relationship [6]. The large lag link is due to that the pH point and the control point of the pH value is not synchronized. In the clarifying process of sugar cane juice, when pre lye inflows into the reaction tank until overflow, the detection point of neutralization juice pH value is reached. On the one hand, this process leads to the non-synchronization of the pre gray pH value and the test point of neutralization pH value. On the other hand, it leads to the large common lag in the process of control. The widely used pH measuring device in the sugar factory is glass electrode [7]. Glass electrode has the characteristics of high precision, fast response and strong stability, which can meet the requirements of complex environment. However, because the experimental equipment with the glass electrode can simulate the research process of pH value intelligent control system in the clarifying process of sugar refinery, it has the disadvantages of high resistance and easy to produce fouling. Therefore, in order to ensure the accuracy and stability of the measurement, the glass electrodes must be cleaned periodically [8]. Aiming at the problems existing in pH value measurement in sugar factory, based on the complex working environment, Song Yunpeng of Guangxi University designed the pH value measurement circuit, and successfully solved the pH measurement system exist impedance matching and electromagnetic interference and other problems, which could quickly and accurately collect the pH value of sugarcane juice. However, by analyzing the technological process of the clarifying process of the sugar refinery, it is found that the pH value measurement itself is a nonlinear link, and the pH control part has the characteristics of uncertainty and large lag.

It is difficult to solve the nonlinear and large lag of pH value. Therefore, pH control is recognized as one of the most difficult processes to control. In view of the difficult control problems of the pH value in the clarifying process of the sugar factory, a set of pH value computer integrated control system was developed by Wu Minghua of South China University of Technology, and it was put into operation in Guangdong Lecong sugar refinery. It could solve the problem of pH value control in the clarifying process of sugar refinery, and the control quality of pH value in neutralization process was greatly improved [9]. Later, Huang Xueying and other people made further improvements to the SS983 type neutralization pH automatic measuring control system, and a series of tests were carried out on the improvement of the measurement part, host circuit design, updating of electronic components, control software, the cleaning system and the ash additive, the selection of the ash adding controller, and the change of the technological process. In addition, they launched a new version. It has been proved by the practice of more than 20 sugar factories that in addition to the original advantages of the new system, the system also has a strong anti-interference ability, long electrode life, gray control more reasonable, and juice pH more stable, and smaller fluctuations [10]. Huacheng auto control equipment factory in Qinzhou designed the pH automatic detection device of double glass electrode. The system used double glass electrodes to measure and clean in turn, which solved the problem of glass electrode measurement accuracy reduction caused by the glass electrode fouling. It has improved the accuracy of pH measurement in sugar factories, and has been applied in many sugar factories in Guangxi, Guangdong, Yunnan and other provinces. The following diagram in Fig. 1 describes the process of sulfurous acid process.

2.2. The development and application of fuzzy control

Control fuzzy is a computer digital control technology based on fuzzy set theory, fuzzy linguistic variables and fuzzy logic inference. In 1965, the famous American expert L. A. Zadeh established the fuzzy set theory based on control theory. In 1973, L. A. Zadeh defined the fuzzy logic control and related theorems of University of Cambridge. In 1974, at the University of Cambridge, E. H. Mamdani's fuzzy controller realized the application of steam engine control for the first time [11]. Through the analysis of the basic process of the water crisis in the chemical plant of University of Electronic Science and Technology in 2002, MATLAB fuzzy tool was used to reflect the pH control simulation based on the characteristics of big inertia and pure lag. And the simulation results showed that fuzzy control could achieve good control effect. In 2007, Cao Youwei of Dalian University of Technology analyzed the problem of pure hysteresis in the process of large inertia temperature control. The fuzzy temperature controller was designed based on 89C51 single chip microcomputer, which solved the problem of difficulty in tuning the PID parameters of temperature control [12]. The waste water treatment system with pH value had the characteristics of large inertia, pure time delay, nonlinear and fuzzy control, which was combined with the prediction of Smith. The fuzzy controller was established to control Smith sewage treatment system pH, using Simulink simulation, which had good control effect [13]. In 2010, Li Gang of Central South University applied fuzzy control into the dual tank water level control, to compare the control effect of the traditional PID algorithm and fuzzy control algorithm in the dual tank water level control, and it was proved that fuzzy control was more conducive to solving the problems of large lag and nonlinearity in the level control. In the same year, Xie Shihong of Shaanxi University of Science and Technology proposed a fuzzy PID control algorithm for on-line adjustment of parameters in view of the nonlinearity and hysteresis of acid-base neutralization process. The method adjusted the parameters of the PID controller on-line according to the real-time deviation of the control process, and analyzed the deviation and deviation change rate to set the fuzzy rules [14]. Experiments showed that the method could adapt to the global change of pH value and overcome the influence of fluctuation of acid-base neutralization flux. In 2011, Wang Baolu of Guangxi University designed fuzzy logic PID controller based on OPC technology and applied it to pH value control in clarifying process of sugar refinery. The experimental results showed that the fuzzy logic PID control had a

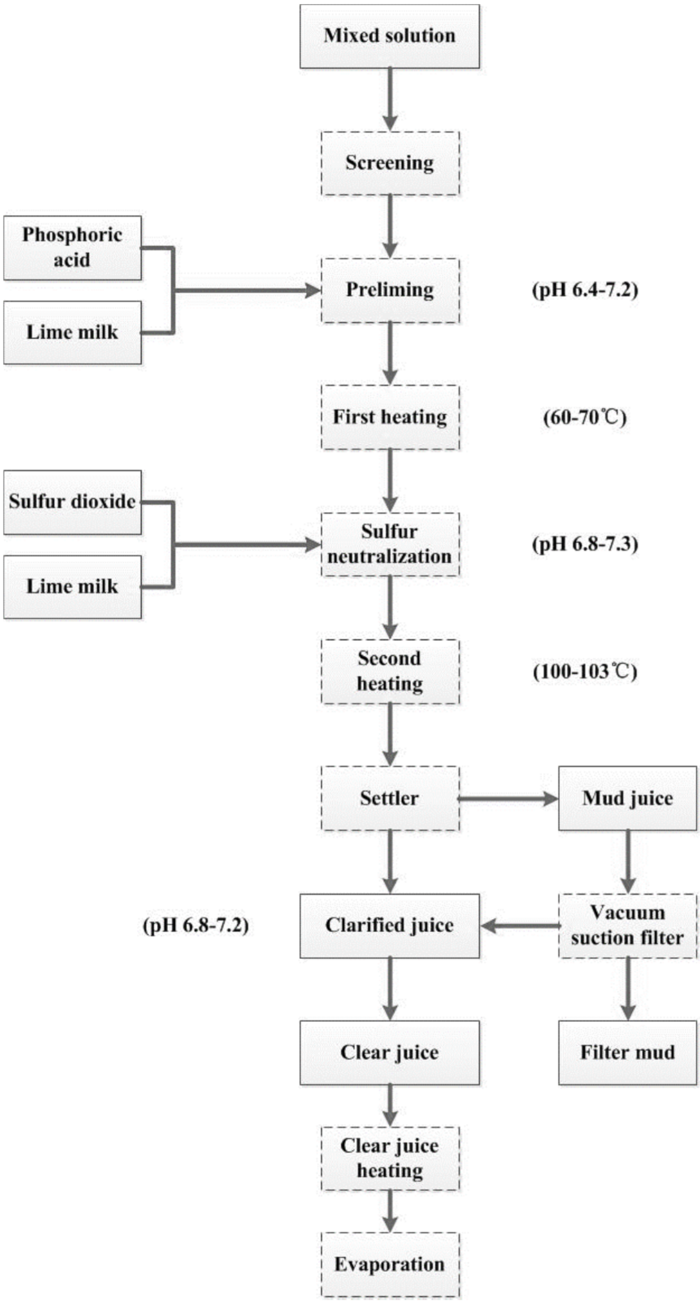

Fig. 1. Process flow diagram of sulfurous acid process

good control effect on the pH value in the clarifying process of the sugar refinery, and it also had certain application value. In the same year, Yan Feng of Beijing Technology and Business University analyzed the time variation and hysteresis in the air conditioning system, and designed and simulated the parameter self-tuning fuzzy controller in the environment of the MATLAB software based on the basic characteristics of fuzzy control technology and classical PID control. The experimental results showed that the controller had faster response and smaller steady-state error [15]. In 2003, Li Hongzhong in Lanzhou Jiaotong University applied the fuzzy control method into the intelligent traffic light system. By controlling the traffic rate of the single intersection, the average delay time of the waiting traffic was reduced, and the environmental protection, energy saving and economic access were realized.

3. Methodology

3.1. Fuzzy adaptive PID control

Figure 2 shows the composition of the fuzzy controller.

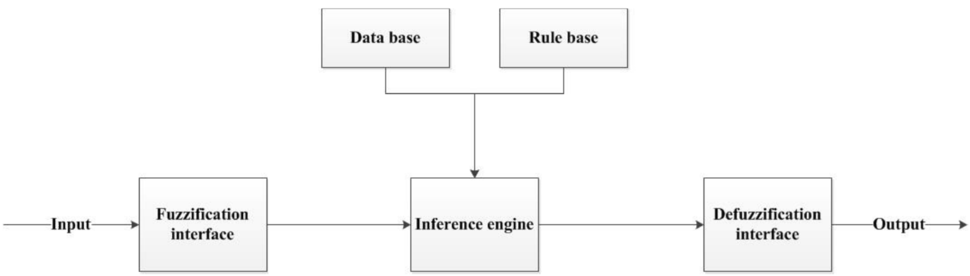

Fig. 2. Composition of fuzzy controller

By calculating the current system error and the rate of error change, fuzzy rules are used to carry out fuzzy reasoning, and the parameters are adjusted after defuzzification. The core of fuzzy PID control design is to summarize the technical knowledge and practical experience of engineering designers, and to establish the appropriate fuzzy rules table. The output values of the control quantity are adjusted respectively according to the three parameters of scale, integration and differential. The fuzzy adaptive PID controller has a deviation of e and a deviation change rate Δe, and the outputs are ΔK_{p}, ΔK_{i} and ΔK_{d}. Among them, G_{l} and $G_{\Delta\mathrm{l}}$ are quantization factors, G_{Kp}, G_{Ki} and G_{Kd} are scale factors, and the range is selected according to the input and output range of objects. Quantities ΔK_{p}, ΔK_{i} and ΔK_{d} obtained by fuzzy inference that adapts to the control object are as the parameter increments of K_{p}, K_{i} and K_{d}, respectively. According to the state of the controlled object, the PID parameters can be adjusted on-line. The fuzzy adaptive PID controller adjusts the PID parameters as follows:

$$K_{\mathrm{p}} = K_{\mathrm{p}}' + \Delta K_{\mathrm{p}}\,,$$

$$K_{\mathrm{i}} = K_{\mathrm{i}}' + \Delta K_{\mathrm{i}}\,,$$

$$K_{\mathrm{d}} = K_{\mathrm{d}}^{'} + \Delta K_{\mathrm{d}}\,, \tag{1}$$

where $K_{\mathrm{p}}^{'}$, $K_{\mathrm{i}}^{'}$ and $K_{\mathrm{d}}^{'}$ are the initialized PID parameters.

The fuzzy adaptive PID finds the fuzzy relation between the three parameters of the PID and the deviation e and the deviation change rate Δe. During the operation, the three parameters are modified online according to the fuzzy control principle by continuously detecting e and Δe. When the control parameters are different, the controlled object has good dynamic and static performances.

3.2. Hardware design of control system

The hardware platform of the control system mainly includes PC104 industrial control computer, pH value detection and control module, temperature detection, control module, and flow detection module. The hardware structure of the control system is shown in Fig. 3.

PC104 is an industrial computer bus standard specially defined for embedded applications. The PCM-3587, PCL-2101 and PCL-9402 modules used in this paper all support the PC104 bus standard. Therefore, in the hardware design of the control system, the three are connected in stack mode to form an industrial controller based on the PC104 bus standard. The core control part adopts PCM-3587 industrial control board which is produced by Dark blue Science and Technology Ltd. It is a low power X86 embedded motherboard designed for PC104 industrial computer bus standards. CPU uses DM&P SOC Vortex86DX, and integrates the north bridge, the south bridge, SPI, BIOS, LPC, serial/parallel port, high-speed USB2.0, OTG, Ultra-DMAIDE, and lOM/lOOM ethernet. The Vortex86DX processor uses an external display chip. This is an ultra-low power graphics chipset with a total power consumption between 1 and 1.5 W, supporting the VGA display resolution of 1600×1200. PCM-3587 has good downward compatibility, which is widely used in the field of embedded development. In the field of hardware requiring small volume, low power consumption and low cost, the modules based on PC104 bus standard have been widely used.

3.3. Software design of control system

The software realization of the control system mainly includes the design of the monitoring interface, the communication between the host computer and the lower computer, and the design and embedding of the control algorithm. The monitoring interface design contains Kingview monitoring design and touch-screen human-computer interaction interface design. The Kingview monitor design part realizes the connection between Kingview and database, and it can monitor real-time data and historical data query. Touch-screen design can achieve real-time display of online data, manual control and automatic control switching. The .dll file of the fuzzy controller is written in the VC++6.0 environment. The .dll file is embedded in the VisSim simulation modeling software, and the temperature control module and the pH value control module are set up. The software framework of the control system

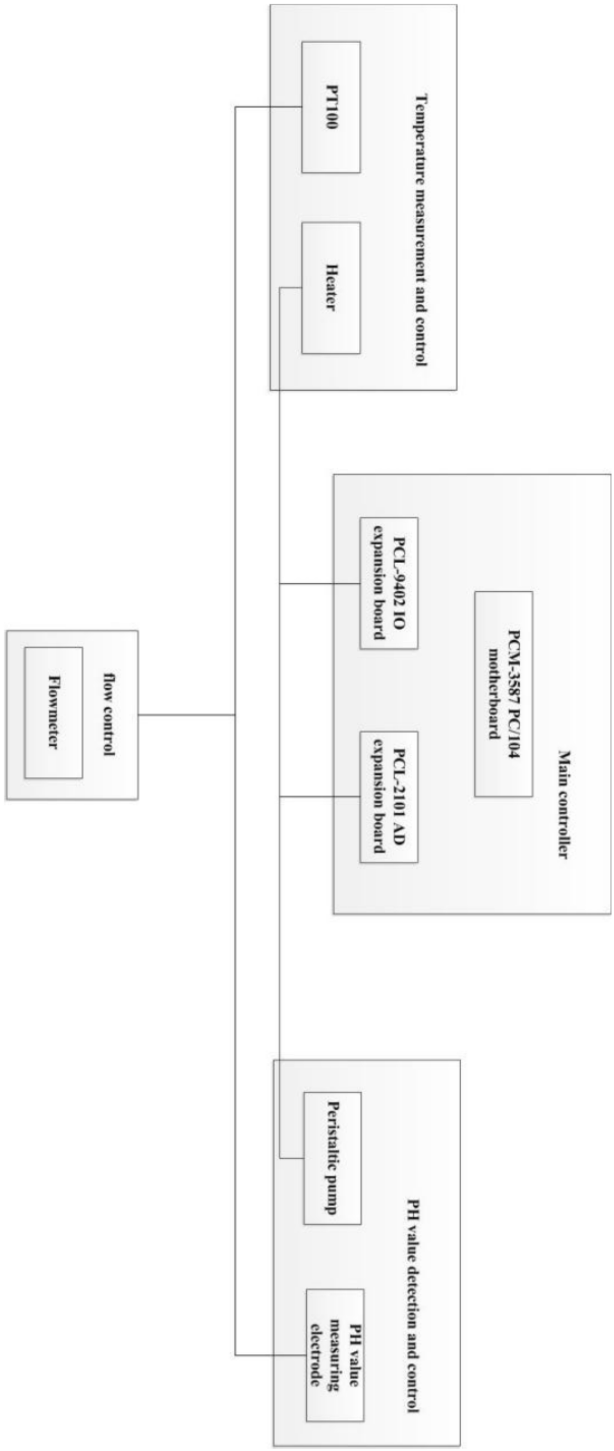

Fig. 3. Hardware structure of the system

is shown in Fig. 4.

The Modbus protocol was the first global bus protocol for industrial sites invented by Schneider electric in 1979. The protocol supports traditional RS-232, RS-422, RS485, and Ethernet devices. At present, many industrial devices use Modbus protocol as communication standard. The controller communicates with the host computer using the Modbus RTU protocol. The Modbus RTU protocol uses a master-slaver query mode. On a communication line, the host sends a query command from the machine to determine whether to reply the message by analyzing whether the command is sent to itself. In the control system, each slaver has a unique address. As a result, the same query instruction does not correspond to multiple responses. In the VC++6.0 environment, the driver programs of the controller are developed to realize the communication with the host computer ModbusRTU. The implementation process of communication is as follows.

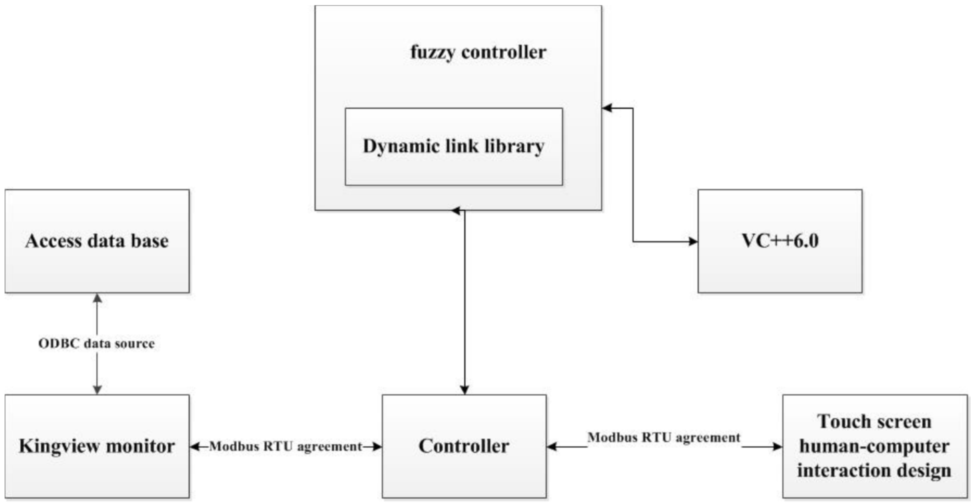

Fig. 4. Software function framework

The format of the Modbus RTU message frame is shown in Table 1.

Table 1. Format of message frames

Address field	Function domain	Data domain	Check field
1bit	1bit	N bits	2bits

4. Result analysis and discussion

The pre lye was sent into the reaction tank through the direct current to simulate the lagging link of actual production in sugar factory. According to the error and the error change rate of the measured value and the given value of the neutralization juice, the pH fuzzy controller obtained the control output by querying the fuzzy rule table. The PWM wave pulse was used to regulate the flow of alkaline juice, and the pH value of neutral juice was stable near the desired index. Before the pH value control experiment, the pH value measuring and controlling device was used to measure several buffer solutions with different pH values. The purpose of the test was to test the sensitivity and accuracy of the glass electrode for different pH values. The buffer value of pH was 9.18, 6.86 and 4, respectively; disodium hydrogen phosphate, sodium tetra borate and dipotassium hydrogen phosphate were used to prepare the buffer solution. The glass electrode was placed in a neutral solution for 1–2 minutes before the experiment, with the purpose to ensure that the surface of the glass electrode was cleaned and to remove the residual solution before. The glass electrodes were successively placed in solutions with pH values of 4, 6.86 and 9.18. The detection effect is shown in Fig. 6.

As shown in Fig. 6, at the initial time, a glass electrode was used to detect a buffer solution of pH value of 4, and the pH value was about 3.93, and the error was about 1.7 %. After 1 minute, the glass electrode was placed in a buffer solution of pH 6.86, and the response time was about 10 seconds; then the pH value increased gradually, and it finally stabilized at about 6.9 with the error of 0.6 %. When the pH value was stable, the glass electrode was placed in a buffer solution of pH 9.18, the response time was about 8 seconds, and the pH value was detected to be about 9.15 with the error of 3 %. The experiments were repeated, and it was found that the experimental results were basically consistent with the first one. PH measurement results showed that the performance of glass electrode, pH signal acquisition board and signal amplifier board was reliable, and the hardware part of pH detection met the design requirements.

PH value fuzzy controller was adopted to control pH value of neutralization juice. In order to simulate the change law of pH value in clarifying process of sugar refinery, a hydrochloric acid solution with a pH value of 6.5 was used to simulate the pre lye, and the sodium hydroxide solution with a pH value of 12.8 was used as neutralization reagent to control pH value of neutralization juice in the experimental process. The given value of neutral juice was 7. Experimental results are shown in Fig. 7.

According to the test results of the temperature control in Fig. 8, in the course of the experiment, the 1800 W electric heater was used to control the pre lye. In the initial state, the temperature of pre lye was 32 °C or so, and the temperature setting index of pre lye was 65 °C. The traditional PID control method was used to control the temperature, and the temperature of pre lye generated fluctuations. The stability of PID control effect was better than that of fuzzy control when the system was in steady state. Experimental results show that the pre lye temperature control fuzzy control algorithm had good control effect.

5. Conclusion

The control of the pH value in the clarifying process of the sugar refinery plays a key role in the quality of the final product of the sugar refining. The lack of automation technology in the production process of the sugar factory has led to low production efficiency and low product yield, which has affected the production and management level of the sugar enterprises. With the continuous development of

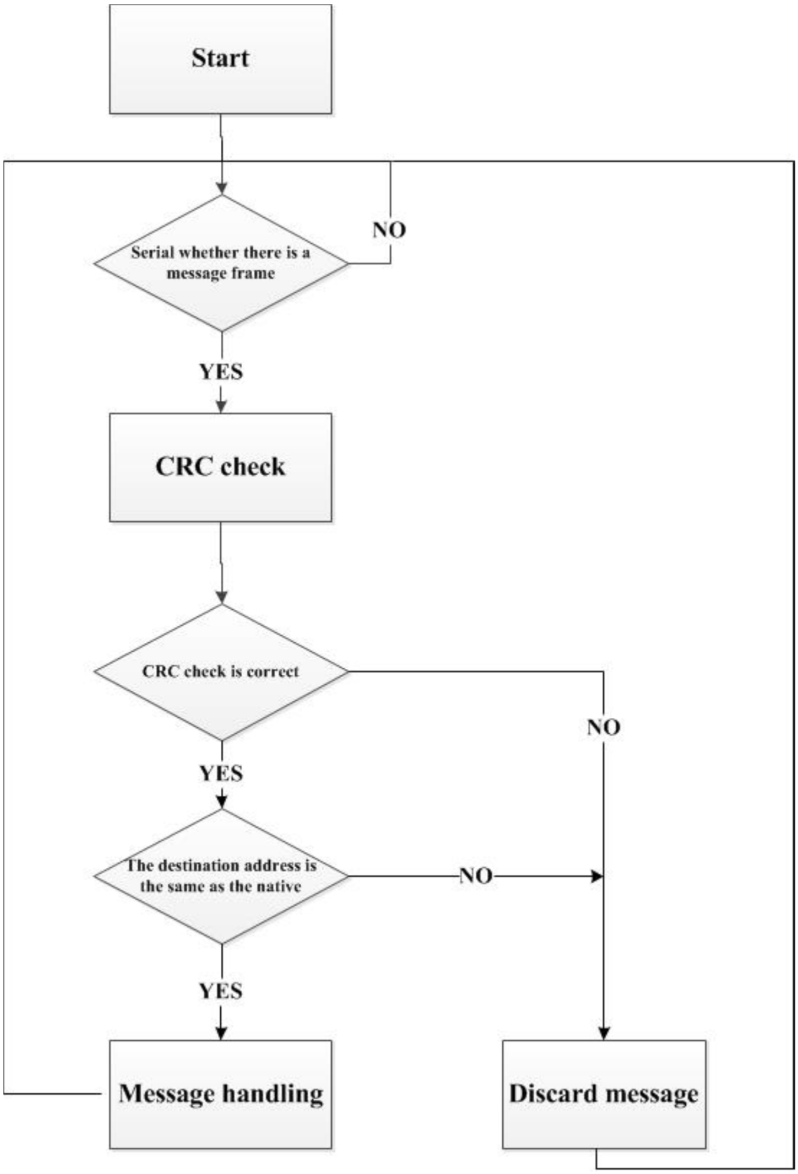

Fig. 5. Modbus communication flow chart

society and the continuous progress of automation technology, it has been promoted in research, application and sugar industry. How to better control the pH value in the clarification section of sugar refinery has become an important problem. In this paper, a pH value intelligent control system was designed on the simulation experimental device in the clarifying process of sugar refinery. The simulation device could truly reflect the actual technological process of the clarifying process of the

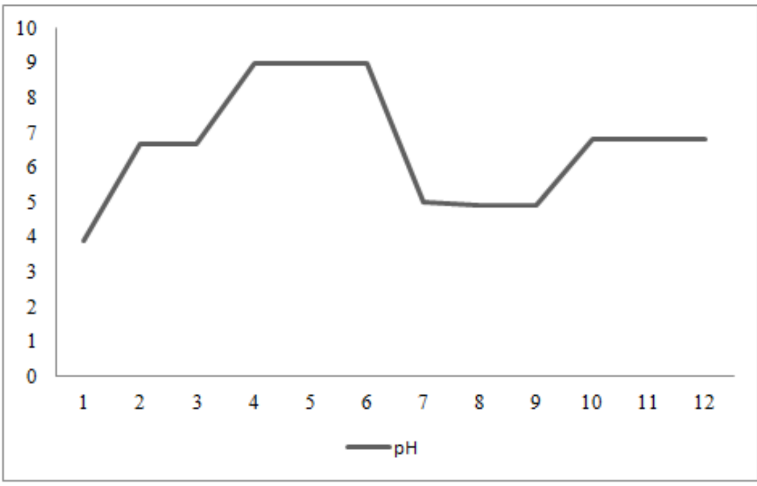

Fig. 6. PH value detection chart

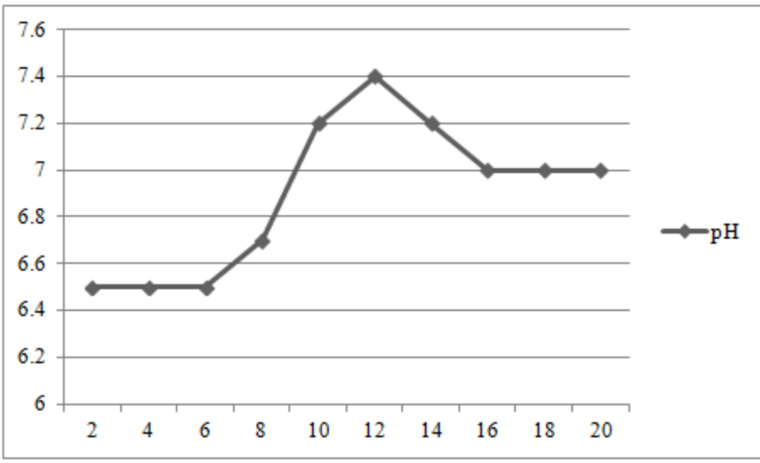

Fig. 7. Neutral juice pH control effect diagram

sugar refinery, and effectively reflect the existing problems. On this basis, the fuzzy control algorithm was used to control the condition index and realize the design of the related hardware system, including AD acquisition program, Modbus communication program, the software design, and the temperature control module. With the help of the pH intelligent control system, the control simulation of the clarifying process of the sugar refinery was carried out, and the control effect of the control system on the pH value and temperature was preliminarily verified. Therefore, the study is of practical significance to improve the research level of pH value control in the clarifying process of sugar refinery based on fuzzy control.

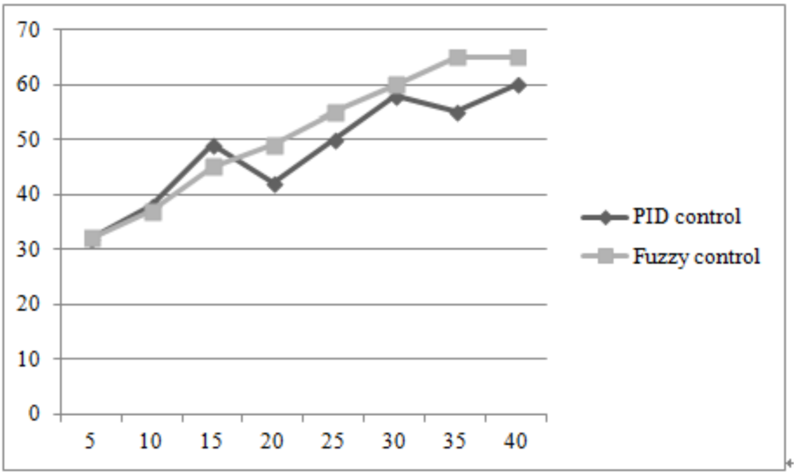

Fig. 8. Temperature control test chart

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