Design of Control System of Alkylation Unit in Petrochemical Enterprise

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Abstract: The temperature and liquid level in the alkylation unit are important factors affecting the product qualification rate, and the control is difficult due to the nonlinearity and hysteresis of the system. A control system with single-chip microcomputer MC9S12XS128 as the core is designed to collect operating data such as temperature and liquid level, and use fuzzy control methods to control it within the required range. The hardware circuit and software structure of the system are designed and tested and verified. The results show that the system has a good control effect and meets the requirements of the device for control accuracy and stability.

1. Introduction

Alkylation is widely used in many chemical production processes and is an important synthetic method for the production of methyl tert-butyl ether (MTBE). MTBE is a colorless, transparent, high-octane liquid. It is an ideal blending component for the production of unleaded, high-octane and oxygenated gasoline. It has been widely used as a gasoline additive all over the world. MTBE equipment has a low utilization rate of automatic control and low control quality. In addition to equipment, technology, management and other factors, the other main factor is the complex process of the refining and chemical equipment, many interference factors, and limited measurable and controllable parameters [1-3]. This type of device generally adopts conventional control strategies such as PID, but for MTBE systems with large lag, strong coupling, non-linear and time degeneration, the control algorithm has certain limitations, resulting in large fluctuations in the process parameters of the device and unstable operation, Which affects the operating efficiency of the device and cannot meet the control requirements. And fuzzy control is one of the effective methods to deal with uncertain objects. It does not need to know the precise model of the object, it can realize the control of the object with nonlinear and large hysteresis characteristics, it has strong adaptability to different process control, has strong robustness, and has a simple structure and easy implementation [4-6]. Aiming at the above situation, the hardware of the MTBE control system is designed, and the fuzzy control strategy is adopted to make the system achieve higher reliability and higher efficiency, and solve many problems that cannot be solved by the linear system control theory.

2. System Overview

A part of the MTBE plant tower is shown in Fig.1. It is called a C4 distillation tower, and its feed is a mixture of C4, methanol and MTBE produced in the previous production process. The inside of the tower is heated to a certain temperature with steam to achieve precise separation of MTBE, C4 and methanol. The product extracted from the bottom of the device tower is the product MTBE. The
temperature and liquid level of the tower are key control parameters, and their fluctuations directly affect the qualification rate of the product. Therefore, the control system must maintain the temperature and liquid level in the tower within a certain range.

Fig. 1 MTBE device tower

3. System hardware design
The control system uses Freescale's 16-bit microcontroller MC9S12XS128 as the core control unit. The temperature transmitter, flow transmitter, and liquid level transmitter collect the liquid temperature, inlet flow rate and liquid level information in the tank respectively, and use signal conditioning circuits. After processing, it is sent to the on-chip A/D of the microcontroller for processing. After the single-chip microcomputer analyzes the collected data, the fuzzy control algorithm is combined to make corresponding adjustments to the electric control inlet valve and the electric control outlet valve to keep the liquid temperature and level in the tank relatively stable. The control signal of the electric control valve is 0~10v, and the voltage is proportional to the opening of the valve. The DAC7715 can output the voltage control signal, and the electric valve is output through the power drive circuit. The opening is adjusted to accomplish the control purpose. The system hardware structure diagram is shown in Fig. 2.

Fig.2 Control system hardware structure diagram

The control system hardware is mainly composed of MCU minimum system with A/D conversion function, signal conditioning circuit, keyboard, LCD display circuit, RS232 communication interface, D/A conversion, electric valve drive circuit, etc. The specific hardware circuit design is shown in Fig. 3.

3.1. Minimum System Of MCU
MCU MC9S12XS128 has 128K flash program space, 8-channel 24-bit interrupt timer, 8-channel 16-bit timer, 8-channel PWM wave output and 8-channel 12-bit precision AD converter; integrated communication interfaces include CAN, SPI, SCI And UART; 16M external crystal oscillator is used, and the highest frequency is multiplied to 96M through the phase-locked loop; the smallest system includes external crystal oscillator, reset circuit and BDM debugging interface circuit. The internal
hardware resources of the single chip microcomputer are abundant, which can fully meet the system design requirements.

3.2. Signal conditioning circuit

The temperature, flow and liquid level transmitters output 4-20mA current signals, and the signal that the on-chip A/D of the single-chip microcomputer can handle is a voltage of 0-5v, so a current-voltage conversion circuit is needed. The system design provides two schemes. One uses a precision resistor with a resistance of 250 ohms and an accuracy of one ten thousandth to convert the 4-20mA current signal flowing through the resistor into a 0-5v voltage signal across the resistor; One scheme adopts the precision current loop receiver produced by American TI Company, which accurately converts 4-20mA input current signal into 0-5v output voltage signal. The two schemes can be switched by jumper wires. In order to prevent the output signal of the transmitter from being subjected to external electromagnetic interference during the transmission process, the converted 0-5v voltage signal is filtered before being sent to the on-chip A/D of the single-chip microcomputer. The operational amplifier TL082 is used to form a second-order low-pass filter, filter cut-off frequency is selected by different values of resistors R4 and R7 and capacitors C48 and C50. The input pin of the A/D of the one-chip computer cannot bear the excessively high voltage, adopts the high-speed switch diode BAV99 to limit the over-voltage under
abnormal conditions.

3.3. D/A conversion
In order to maintain the stability of the liquid level and temperature in the tank, the electric regulating valve should be adjusted and controlled in a timely manner. The electric control valve power supply is DC 24v, and the control signal is 0-10v. The required control signal voltage is generated by the D/A converter DAC7715 to adjust the opening of the electric valve. DAC7715 is a 4-channel voltage output 12-bit D/A converter produced by American TI company. It has an SPI serial interface and can communicate with the microcontroller easily. Its hardware circuit is shown in Fig. 3, where REF01 is a voltage reference source that outputs 10v, which provides a reference voltage for D/A conversion.

3.4. Electric valve drive circuit
The 0-10v voltage signal output by the DAC7715 is not enough to directly drive the electric control valve, and a drive circuit is needed to complete it. The circuit is successfully constructed using high-voltage and high-current operational amplifiers produced by American TI. OPA548 has low power consumption, wide range power supply, good output voltage swing, continuous output current of 3A, maximum 5A, which can fully meet the needs of system design. The hardware circuit is shown in Figure 3. First, the 0-10v voltage signal output by the DAC7715 is passed through a voltage follower composed of an operational amplifier TL082, and its output is used as the input of OPA548. The 6-pin output voltage can be directly added to the electric control valve.

4. Fuzzy control
Aiming at the actual problems in the system, fuzzy control algorithms are used to design corresponding fuzzy controllers to improve the automatic commissioning rate of the device and the smoothness of device operation, thereby improving the quality of product production. The block diagram of the controller structure is shown in Fig. 4.

4.1. Liquid level control
Liquid level control is accomplished by adjusting the outlet flow at the bottom of the tower. Based on the quantization factor \{Nb, nm, NS, 0, PS, PM, Pb\} of liquid level, combined with the difference quantization factor \{Nb, nm, NS, 0, PS, PM, Pb\} of inlet and outlet flow, the fuzzy criterion is established and the control quantity is obtained. On the basis of liquid level as a variable, the detection of tower top flow and reflux flow is increased, and the number of fuzzy subsets is increased by one dimension. Through the comparison of inlet flow and outlet flow, the liquid level rise and fall trend can be predicted first, the timeliness of control system can be enhanced, and the reaction speed of outlet flow control device can be improved to adapt to the characteristics of large delay of the system.

4.2. Temperature control
By measuring the flow of materials entering the reaction tower and adjusting the opening of the steam valve, it can predict the trend of temperature changes, and adjust the amount of steam before temperature
changes to achieve more precise control of the system. On this basis, the temperature error and its rate of change in the reaction tower are collected, and the fuzzy algorithm is adopted to adjust the steam valve accordingly, which can solve the problem of over-adjustment of the liquid temperature.

4.3. Use of decoupling coefficient
Due to the coupling phenomenon between temperature and liquid level, the output after further realization of fuzzy decoupling by introducing a decoupling coefficient is:

\[
U_t = M_t[(1-\beta_1)C_t + \beta_1C_l], \quad (0 \leq \beta_1 \leq 1) \tag{1}
\]

\[
U_l = M_l[(1-\beta_2)C_l + \beta_2C_t], \quad (0 \leq \beta_2 \leq 1) \tag{2}
\]

The control principle is as shown in the figure above. If \( \beta_1 \) and \( \beta_2 \) are set to 0, it is equivalent to two single-loop controls without decoupling. When the value of both is between 0 and 1, the specific value can be determined through experiments. The specific method is to continuously increase the values of the two from 0 during the production process, and take the two values as the best decoupling coefficient when the fluctuation of the parameters in the tower is minimal.

4.4. Fuzzy control rule table
The fuzzy control rule table can be derived from fuzzy mathematics, as shown in Table 1. Calculate the corresponding output value according to the system temperature and its rate of change, and make the matrix relationship into a lookup table. In addition, these parameters can be modified according to actual operating conditions to achieve better control effects.

| e(\degree C) | -3 | -2 | -1 | 0  | 1  | 2  | 3  |
|-------------|----|----|----|----|----|----|----|
| -4          | 10 | 2.0| 1.9| 1.8| 1.7| 1.6| 1.5|
| -3          | 1.8| 1.7| 1.6| 1.55|1.45|1.35|1.3 |
| -2          | 1.65|1.6 |1.55|1.4 |1.25|1.2 |1.15|
| -1          | 1.4 |1.35|1.3 |1.2 |1.1 |1.05|1   |
| 0           | 1.15|1.1 |1.05|1   |0.95|0.9 |0.85|
| 1           | 0.95|0.9 |0.88|0.85|0.83|0.8 |0.75|
| 2           | 0.9 |0.85|0.8 |0.75|0.7 |0.6 |0.5 |
| 3           | 0.7 |0.65|0.6 |0.55|0.5 |0.4 |0.3 |
| 4           | 0.6 |0.5 |0.4 |0.3 |0.2 |0.1 |0   |

5. System software design
The system software adopts a modular design. After the system is powered on, the MCU is initialized first, which mainly includes peripheral port allocation and working status setting, interrupt register setting, serial communication mode and baud rate setting, and SPI setting. According to the data information collected by the temperature, flow, and liquid level transmitters, combined with fuzzy control rules, the corresponding control is completed. The main tasks of the software design are: ① Complete the collection of various variables in the reaction tower; ② Data retrieval, analysis, and calculation; ③ Output the operating voltage of each valve to achieve the control of the liquid level and temperature in the tower; ④ Keyboard input and Temperature display, the software process is shown in Fig.5.
6. Test results

Build a test prototype to collect the liquid level, temperature, and material flow in the device; control the liquid level and temperature; test the communication and monitoring functions between the host computer and the local control unit. The test result is shown in Fig. 6. It can be observed from the figure that the temperature change is controlled within the range of 68±3℃ within 600 minutes, which meets the requirements of technical indicators.

7. Conclusion

This article introduces the working process of the MTBE device. According to the requirements of the production process, a control system based on fuzzy control is designed to control the temperature and liquid level in the reaction device within a reasonable range. The hardware and software are designed, and experimental research has been carried out, and the experimental results show that the method has a good control effect and meets the requirements of the device for control accuracy and stability.

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