

# Research Progress and Prospects of Temperature Control in Chemical Reactors

Jiang Li\*

Hangzhou Hongwei Pressure Vessel Manufacturing Co., Ltd., Hangzhou 311305, Zhejiang, China

\* Corresponding author: JiangLi (Email: 493198065@qq.com)

## Abstract

**Reactors are commonly used reaction vessels for chemical reactions and are widely applied in chemical production. This article introduces the basic structure and working characteristics of chemical reactors, and based on this, proposes the difficult problems in temperature control during the reactor operation process. Subsequently, it elaborates on the working principle of the adaptive fuzzy PID controller and its application scenarios such as temperature alarms and emergency stops. Finally, it further prospects the future research trends of chemical reactor temperature control technology, indicating the direction for future research on reactor temperature control.**

## Keywords

**Reactor; Temperature Control; Chemical Production; Adaptive Fuzzy PID Control.**

## 1. INTRODUCTION

The reactor is a structural form of the chemical reactor. The continuous production of the tank-type reactor can conduct single-phase, homogeneous, and multi-phase reactions. In actual chemical production, continuous production can be achieved. During the process, stirring is used to ensure the full reaction of materials, thereby improving the material utilization efficiency, saving funds, and reducing costs.

With the continuous maturity of production practice conditions, reactors have shifted from manual operation to automation. From material preparation, feeding, and discharging, high-precision preset condition operations are realized during the reaction process, and real-time monitoring is carried out simultaneously[1]. To meet the development needs of the current chemical industry, in the chemical production process, attention should be paid to the temperature control problem, and a temperature control system should be designed to strengthen the temperature control effect of the reactor and meet the requirements of chemical production[2]. Therefore, it is of far-reaching significance to deeply explore and study the reactor temperature control scheme from multiple aspects and continuously optimize its automatic control scheme in actual production.

Traditional temperature measurement inside the reactor generally selects thermal resistors or thermocouples according to the temperature measurement range. They form a control loop with the regulating valve on the pipeline of the heat-conducting medium entering the reactor to achieve the purpose of temperature adjustment[3]. For conventional reactor temperature control, simple PID single-loop adjustment is sufficient. It mainly consists of four major parts: the controlled object (reactor), the detection and transmission device (thermocouple or thermal resistor), the control device (DCS), and the execution and adjustment mechanism (regulating valve). Taking hot water as the heat-conducting medium as an example, when the

reactor temperature does not reach the set value, the hot water inlet regulating valve is opened wider to allow the hot water to fully exchange heat with the materials. When the set temperature is reached, the hot water inlet regulating valve is closed slightly to maintain the material temperature at the set value, thus realizing the automatic control of the entire reactor temperature[4].

However, for some more complex reaction processes, such as first heating the reactor to start the reaction, and then, after the reaction starts, a large amount of heat is released. To ensure the smooth progress of the reaction, the reactor needs to be cooled. In such cases, to achieve the automation of reactor start-up and normal production, a split-range control system must be adopted. In a simple control system, the output of one regulator only drives one regulating valve, while in a split-range control system, the output of one regulator drives two or more regulating valves to work, and each regulating valve only acts within a certain range of the regulator's output signal[5].

When the temperature inside the reactor is lower than the set value, the regulator will command the steam inlet valve to open to heat the reactor. After the reaction starts, as the reaction heat is gradually released, the regulator will gradually close the steam inlet valve and then slowly open the cooling water inlet valve to remove the reaction heat. In this way, from the start of the reaction in the reactor until the reaction is stable, the temperature of the reactor can be kept basically unchanged, thus meeting the requirements of automatic control of the technological process.

## 2. PROCESS CHARACTERISTICS OF CHEMICAL REACTORS

### 2.1. Reactor Structure

The reactor is a stainless-steel container for physical or chemical reactions. Through the structural design and parameter configuration of the container, functions such as heating, evaporation, cooling, and mixing at low and high speeds required by the process can be achieved [6]. The tank-type reactor has two operation modes: batch production and continuous production. The latter is the most commonly used chemical reactor in the industrial production process. It can not only conduct single-phase reactions but also mix solid, liquid, and gas phases for reactions. There is a stirring device inside to ensure the full reaction of the reaction raw materials, avoiding the waste of raw materials and saving production costs.

The reactor is composed of a tank body, a tank cover, a jacket, a stirrer, a transmission device, a shaft seal device, a support, etc. Common stirring forms include propeller-type, turbine-type, paddle-type, frame-type, and anchor-type. When a stirring device with a large height-to-diameter ratio is used, a multi-bladed stirring device is selected. Manufacturers can also design the form of the stirring device according to the actual on-site environment and production process. The heating device of the reactor can be set outside or inside the tank wall. The reactor is heated in a cycle through a jacket or a heat-exchange surface. Generally, the reactor is heated by methods such as heat-conducting oil circulation heating, coil heating, electric heating, and steam heating. The reactor can be cooled by the blades in the stirring device through stirring, or by methods such as coil cooling in the tank or jacket cooling.

### 2.2. Reactor Working Characteristics

In chemical production, reactors are very important production equipment with complex chemical reaction mechanisms. Factors such as the type of catalyst, external conditions, changes in the amount of raw material addition, raw material purity, flow rate changes, and the temperature of circulating water or heat-conducting oil can all affect the reaction. Since the measurement methods for process parameters such as conversion rate during the chemical

reaction process are very complex, controlling the reaction temperature has become an effective way to control product quality[7].

The temperature control of the reactor generally depends on the process system of the chemical reaction. Only by being familiar with the process system can the reactor temperature be well-controlled. Generally speaking, the reactor temperature system consists of the material reaction stage, one or several heating-up stages, a transition stage (where the materials react fully), and one or several constant-temperature periods. This is a complex, non-steady-state, and non-uniformly distributed temperature field. Solving the two problems of the time-varying relationship of the tank temperature and the uniformity of the tank temperature plays a crucial role in temperature control[8]. During the heating-up stage, the tank temperature should change continuously according to a certain time-varying relationship, and the tank temperature has a positive-variable relationship with time. The key issue is how to adjust the tank temperature continuously and accurately in a timely manner.

### **3. RESEARCH ON REACTOR AUTOMATIC TEMPERATURE CONTROL TECHNOLOGY**

#### **3.1. Difficult Problems in Reactor Control**

The difficulties in the reactor temperature control system are reflected in three aspects: non-linearity, delay, and complexity[9]. During a chemical reaction, a series of changes will occur in the heating system, and the entire process is very susceptible to the influence of the external environment. In addition, the change trends during the reaction process are significantly different, making the reactor a non-linear system. The reactor is characterized by a large volume and heat capacity and can undergo endothermic and exothermic reactions at any time. Therefore, the data collection process takes a long time. When a polymerization reaction occurs in the reactor, the chemical raw materials are changing, resulting in changes in the process and substances, and a series of endothermic and exothermic reactions occur. Therefore, chemical production itself is very complex[10,11].

#### **3.2. Working Principle of Automatic Temperature Control**

Traditional temperature control uses a traditional PID controller, which is difficult to achieve effective control results. After continuous optimization and improvement, the adaptive fuzzy PID control technology is applied, and an adaptive fuzzy PID controller is used. Through fuzzy inference, the PID parameters are adjusted online to achieve effective temperature control. Judging from the actual application effect, when the adaptive fuzzy PID controller is used to control the reactor temperature, the parameters can be optimized and adjusted according to the actual changes in the system deviation and the deviation change rate. It has good adaptability and robustness and can achieve the purpose of high-precision control of the reactor temperature[12].

### **4. APPLICATION RESEARCH ON REACTOR TEMPERATURE CONTROL**

In the process of chemical production, it is very difficult to control the temperature inside the reactor. In chemical production, if the temperature inside the reactor is too high, the pressure in the reactor will increase. As the pressure increases, there is a high risk of explosion. Therefore, it is necessary to be able to issue an alarm signal in a timely manner when the pressure in the reactor becomes too high due to excessive temperature, so that workers can take timely measures to avoid greater accidents and unnecessary losses and injuries. For this reason, it is necessary to design an alarm device and an emergency stop device in the temperature control system.

To improve its safety and reliability, not only automatic control but also manual handle control should be used in combination[13]. Its working process is as follows: as the temperature inside the reactor continues to rise, the pressure inside the reactor gradually increases. The pressure measurement system connected to it will transmit the pressure inside the reactor to the alarm device. When the transmitted data is greater than the data set by the alarm device, the alarm device will send an alarm signal to the workers, and at this time, the automatic stop device will also be activated to avoid dangerous events. After stopping, corresponding measures need to be taken. First, the feed valve should be closed in a timely manner to prevent reactants from continuing to enter the reactor. Second, the serpentine cooling pipe should be opened to increase the amount of cooling water, ensuring that a large amount of cooling water enters the cooling pipe to quickly reduce the temperature in the reactor. Third, the discharge valve should be opened to empty the reactants and products in the reactor in a timely manner[14]. These systems exist independently during the reaction process, and each system has both automatic and manual control methods. After the alarm device issues an alarm, these processes can also be manually operated when necessary.

In summary, the reactor temperature control system has a wide range of applications in the chemical industry. Through its applications in temperature alarms and emergency stops, it not only provides high-precision control and safety but also helps to improve energy utilization efficiency and environmental protection[15].

## 5. SUMMARY AND OUTLOOK

Chemical reactors themselves are characterized by large volumes and thick walls. The actual chemical reactions carried out inside the reactors are often complex. Coupled with the interference of other external factors such as cold/hot water and external equipment, there are problems such as strong time-variability, hysteresis, non-linearity, and difficulty in modeling in the temperature control of reactors[16]. The traditional PID control has a simple principle, is easy to implement, and requires a precise mathematical model. However, when directly applied to the temperature control of reactors with complex mechanisms and difficult-to-establish precise models, the control effect is not satisfactory. Fuzzy control formulates fuzzy rules based on the experience and laws summarized in actual production and conducts fuzzy inferences. It can resist interference and adapt to parameter fluctuations to a certain extent. However, with the deviation and deviation change rate as inputs, there are problems such as low control accuracy, large steady-state errors, and slow adjustment times[17]. Predictive control has low requirements for model accuracy and good dynamic optimization performance, but it has problems such as complex theoretical analysis, difficult control law solution, and weak control stability[18]. Neural network control does not require the establishment of a precise mathematical model and can perform online self-learning optimization. However, there are problems such as difficulty in selecting network parameters, poor interpretability, and difficulty in determining the network structure[19]. Therefore, it is difficult to achieve precise control of the temperature of continuously stirred reactors using only a single control method. In the future, it is necessary to fully combine the advantages of several control methods. For example, by combining the parameter self-optimization of intelligent optimization algorithms, the adaptive learning of RBF neural networks, the dynamic rolling optimization of predictive control, and the model-free advantage of fuzzy control, a more excellent comprehensive temperature control method for continuously stirred reactors can be designed. This will be a hot research direction for the temperature control of continuously stirred reactors in the future.

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