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Advanced The Quality of Temperature Control of Batch Reactor using The Hybrid Fuzzy Controller

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Abstract

Batch reactors are widely used in the processing industry, chemicals, and pharmaceuticals. To create output for batch reactor concentration and quality assurance following design productivity, we need to control the reactor's temperature following technological requirements. Characteristics of the process in a batch reactor is a nonlinear system, not working at an equilibrium that works mainly in the dynamic process. Content in this paper, we use a hybrid fuzzy controller to control the temperature of batch reactors.

Keywords — *Batch Reactor, fuzzy controller, hybrid fuzzy controller.*

I. INTRODUCTION

Batch reactors are common in small sizes, has better kinetic properties than the continuous reactor because it has a slower reaction rate, resulting in better product quality. Figure 1 is a schematic diagram of the general principle of a batch reactor, which works in a cycle: Load material, start up, operate, stop disassemble, clean it, and go on to the next batch [1].

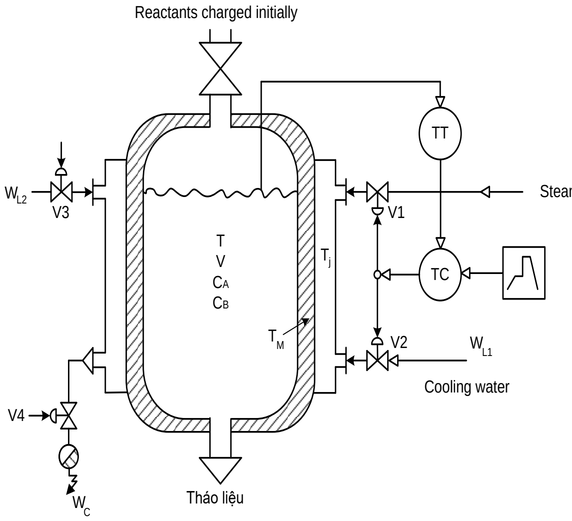

Figure 1: Batch reactor [1]

The main part of the batch reactor includes: Reactor with volume V containing the reaction solution, the reaction solution fed into the flask with a concentration of C_{A0} and a temperature of T_1, the finished product removed with concentration C_B and T temperature; The case of the device is composed of a Jacket type, and heat is transferred through the wall of the reactor. According to the technology, the chemical reaction in the furnace depends on the temperature control according to the program Td decided. To ensure temperature control, the furnace has two heating lines: saturated steam through valve V_1 for heating, cold water source to reduce heat through valve V_2. These two valves are controlled by a T_c temperature controller with a set T_c according to a predetermined program. Two valves V_3 and V_4, for draining cooling water and condensate.

The problem is that the reactor temperature should be controlled to stick with the set temperature to ensure the product's concentration and temperature after the reaction. Document [2] used a PID controller to control the temperature of the reactor. The results of [2] show that the quality of control still has a large deviation and over-regulation. In [3], an adaptive controller was used to control the temperature in the oven to improve the quality of control. The simulation results of [3] show good control quality, but the object model of [3] is linear while the object is nonlinear. The paper uses a PI law hybrid fuzzy controller to control the temperature of the reactor. The simulation results of the paper have good control quality, no over-regulation, and small static deviation.

II. RESEARCH SUBJECTS

A. Hydrolysis Reaction Acetic Anhydride

To concretize the control problem, consider the hydrolysis reaction of Acetic Anhydride in the batch reactor to create Acetic Acid. Acetic Acid is used in various fields in the industry, such as the production of acetate salts, plastic compounds, pharmaceuticals, dyes, food, and food additives.

Equation of hydrolysis reaction of Acetic Anhydride is as follows [4]:

$$(CH_3CO)_2 O + H_2O \rightarrow 2CH_3COOH \qquad (1)$$

The reaction is performed in a batch reactor [5]. The symbol of material entering the furnace is substance A, and the output product is to be collected as substance B. Substance A is fed into the oven with the concentration of C_{A0}=50kg/m^3 (0,49 mol/l), the temperature T_1=278K (5^0C) after the reaction obtained, compound B has concentration C_B = 100 kg/m^3 = 0,98 mol/l, T = 278K. The set temperature in the oven is illustrated in Figure 2. The set temperature program has two phases:

- (0 - 1000s) T_{max} set temperature (313K) is the heating stage for the reactor (heating).

- (1000 - 2400s) temperature attenuation is the cooling stage for the reactor (cooling).

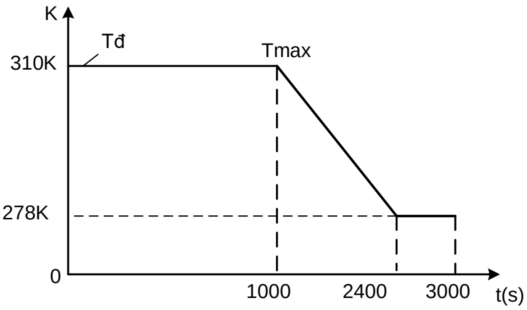

Figure 2: Reactor set temperature

B. Batch Reactor Dynamics

Balance chemical equation [4], [5]:

- For substance A:

$$V\frac{dC_A}{dt} = -Vk_1C_A \quad (2)$$

- For substance B:

$$V\frac{dC_B}{dt} = 2Vk_1C_A \quad (3)$$

- Reaction speed coefficient:

$$k_1 = k_0\exp(-\frac{E_1}{RT}) \quad (4)$$

- Equation of reactive heat equilibrium:

$$\rho VC_p\frac{dT}{dt} = -Vk_0e^{-\frac{E}{RT}}.\Delta H.C_A + k_TA(T_j - T) \quad (5)$$

The heating is done by introducing saturated steam through valve V_1 into the jacket; cooling is done by passing cold water through valve V_2 into the jacket (Figure 1). We have the Jaket thermal equilibrium as equation (6):

$$\rho_jC_{pj}V_j\frac{dT_j}{dt} = F_j\rho_jC_{pj}(T_v - T_j) + K_TA\left(T_J - T\right) \quad (6)$$

Where: V(m^3) is the device volume, C_A and C_B (mol/l, kg/m^3) are the input and output concentrations of the reactant, T_1(K) is the input temperature of the reactant, T(K) is the reaction temperature, T_v(K) is the input temperature of the jacket, k_1(s) is the reaction rate. K_T is the heat transfer coefficient (W/m^{2}K), A heat transfer area (m^2), T_j(K) temperature of the jacket, ρ(kg/m^3) is the density of the reactant, C_p (J/kg.K) is the specific heat of the reactant.

The T_c temperature controller supplies the voltage signal U to control the opening of valves V_1 and V_2. The temperature entering the jacket is calculated using equation (7).

$$T_v = \frac{T_{max} - T_{min}}{U_{max} - U_{min}}U + T_{min} \quad (7)$$

Where T_{min} is the temperature of the cold water source, T_{max} is the saturated steam temperature.

Equations (2), (3), and (4) show that the output concentration of the reactor depends on the reactor temperature according to the reaction rate. The dependence of C_A, C_B on T is a nonlinear function (function exp). The reactor temperature did not work at equilibrium but mainly during the dynamic. The problem poses that the temperature control needs to be following the technology's requirements, as shown in Figure 2, to ensure product concentration.

III. DESIGNING THE TEMPERATURE CONTROLLER FOR BATCH REACTOR

A. Build An Object Model

Model component equilibrium (2), (3) according to Figure 3. Reaction speed model (4) is shown in Figure 4.

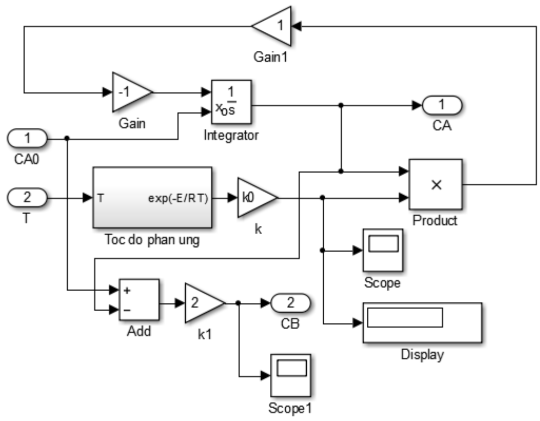

Figure 3: A component equilibrium simulation model

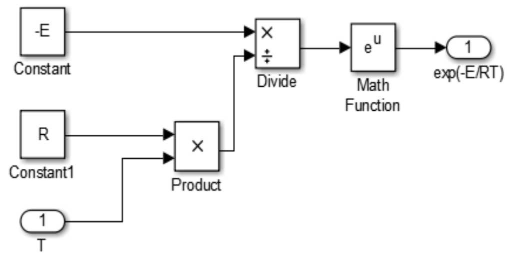

Figure 4: Reaction rate model

The simulation model of reactive heat balance (5) is shown in Figure 5. The simulation model of jacket heat balance (6) is shown in Figure 6.

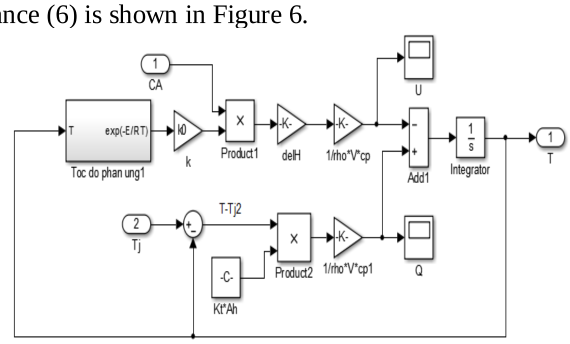

Figure 5: A simulation model of the reactor thermal equilibrium process

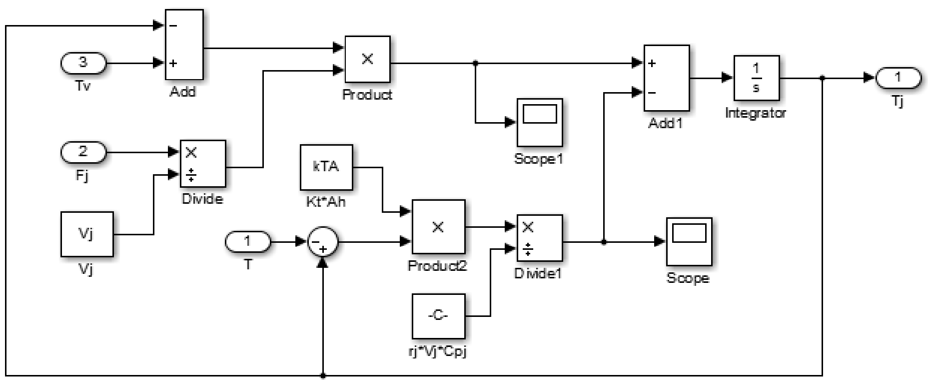

Figure 6: A simulation model of the Jacket heat balance process

The reactor system's simulation model is built from the simulation models from Figure 3 to Figure 5. Figure 7 is the simulation model of batch reactor equipment.

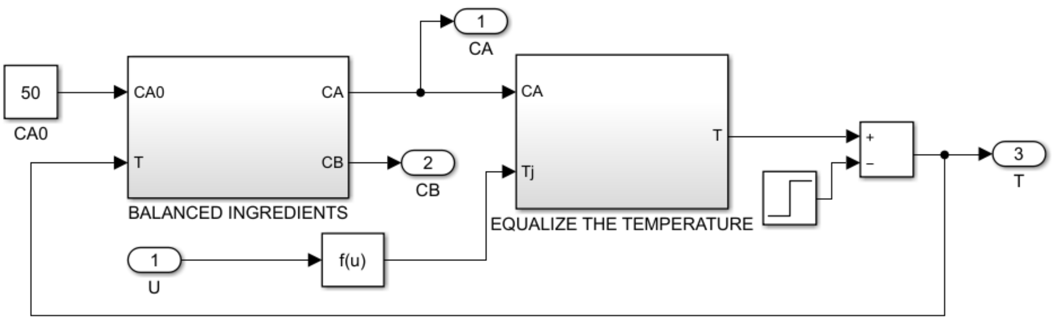

Figure 7: A simulation model of reactive equipment system

Initial batch reactor parameters are given as follows: Reaction solution volume $V=0,508.10^{-3}m^3$. Equipment bottom area $S=0,00635m^2$. Solution concentration of raw material (input) $C_{A0}=50kg/m^3=0,49mol/l$. Product solution concentration (output) $C_B=100kg/m^3=0,98$ mol/l. Reaction energy E=53408J/mol. Heat of the reaction ΔH=142000J/kg. The ideal gas constant R = 8,314J/mol.K. Specific heat capacity of reagent C_p = 4200J/kg.K. Density of reaction medium $\rho=1000kg/m^3$. Saturated steam at 353K (80°C) through V_1 valve, and cold water temperature 273K (0°C) through V_2 valve. In which valves V_1, V_2 are controlled by control signal (0-10V), corresponding temperature is fed into the reactor (273-353K).

B. PID Controller Design

The PID controller simulates the batch reactor temperature as shown in Figure 8, with the systematic treatment sampling period T = 1s.

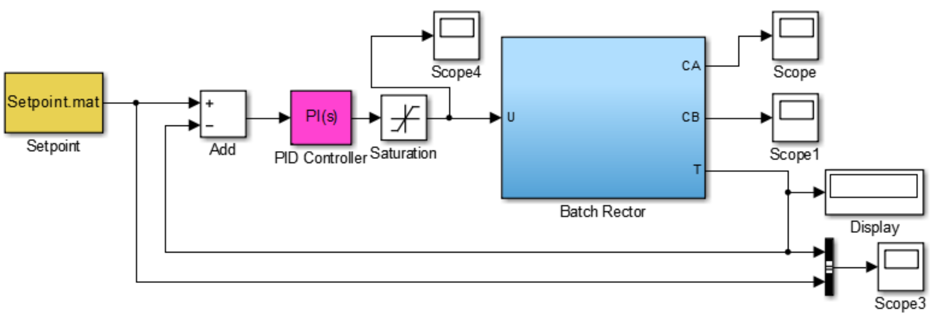

Figure 8: Simulating model of PID controller controlling batch reactor temperature

The problem is temperature adhesion control, so choose a PI controller like (8).

$$R(s) = k_p + k_I \frac{1}{s} \qquad (8)$$

Parameters k_p and k_I are selected according to the second Ziegler - Nichols method [6] and combine with the parameter setting through simulation. PI controller parameters selectable have the following values: k_P = 12 and k_I = 0,001.

C. Design P.I. hybrid fuzzy controller

Fuzzy control uses the subject's experience and control processes of experts in the control algorithm, so the fuzzy control system is a step closer to human thinking. Simultaneously, when the system has variable parameters not exactly defined, fuzzy control is an option.

Fuzzy-hybrid is an automatic control system in which the control device consists of two components [7]:

- Classic controller (usually a PID controller);
- Fuzzy controller.

The structure of the hybrid fuzzy controller is shown in Figure 9.

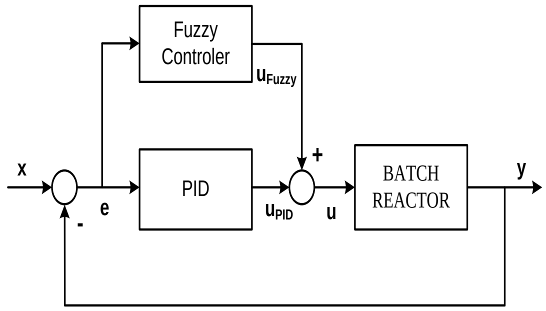

Figure 9: Structure of the PI hybrid fuzzy controller

The control algorithm of the PI hybrid fuzzy controller is like (9).

$$u = u_{PID} + u_{Fuzzy} \qquad (9)$$

The fuzzy controller used is a PI law controller, designed as shown in Figure 10. In which the K_1, K_2, K_3 are the coefficients for pre-processing and post-processing.

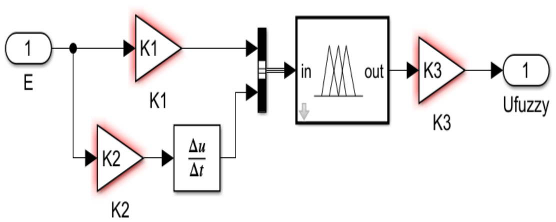

Figure 10: Structure of fuzzy controller according to PI law

The fuzzy controller consists of two input signals: E deviation, deviation DE derivative, and one output signal DU. (Figure 11).

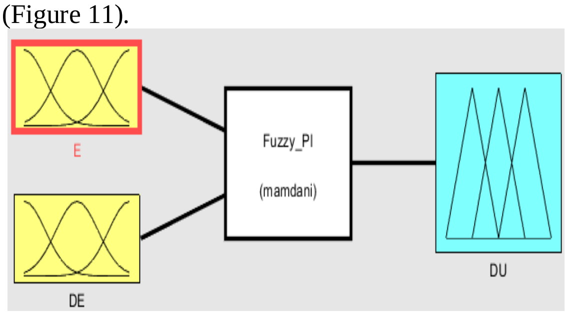

Figure 11: Structure of the fuzzy controller

Blur the output of the fuzzy controller as shown in Figure. 12, Figure. 13, Figure. 14. The fuzzy controller uses the MAX-MIN composite device and de-blurring according to the center-weight method.

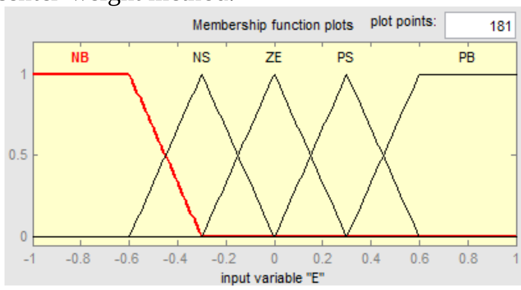

Figure 12: Fuzzy input E

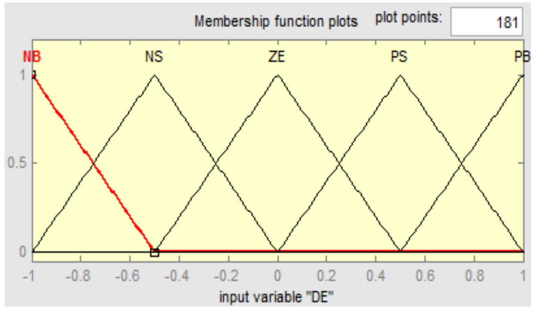

Figure 13: Fuzzy input DE

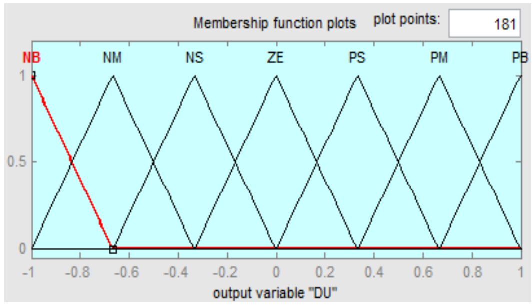

Figure 14: Fuzzy output DU.

The fuzzy rule table is constructed in Table 1.

Table 1. Fuzzy law table

DU.		E				
		NB	NS	ZE	PS	PO
DE	NB	NB	NB	NM	NS	ZE
	NS	NB	NM	NS	ZE	PS
	ZE	NM	NS	ZE	PS	PM
	PS	NS	ZE	PS	PM	PB
	PB	ZE	PS	PM	PB	PB

The fuzzy controller input/output relation is shown in Figure 15.

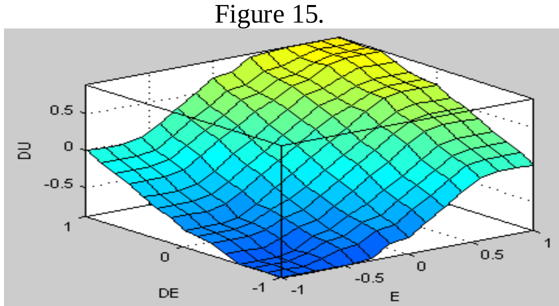

Figure 15: Input/output relation to fuzzy controller

The normalization coefficients of the fuzzy controller are as follows: K_1=1; K_2=0,5, K_3=4. The simulation model uses a PI hybrid fuzzy controller to control the reactor in batches, as shown in Figure 16.

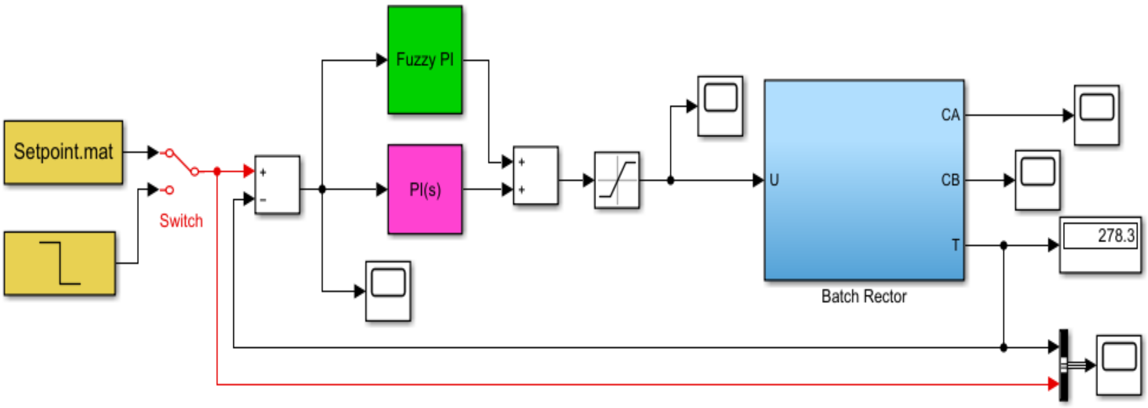

Figure 16: Simulation model using PI hybrid fuzzy controller

The control quality of the hybrid fuzzy controller is illustrated in Figure 17. The graph comparing the quality of the hybrid fuzzy controller PI with the classic PI controller is illustrated in Figure 18.

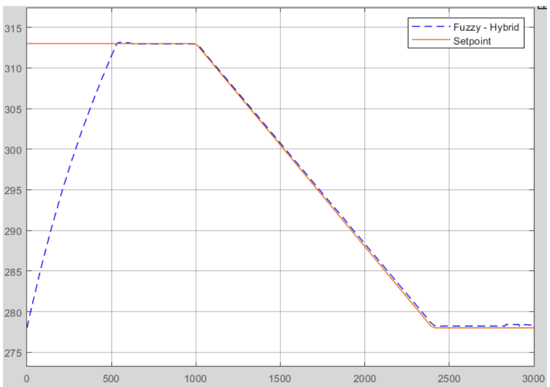

Figure 17: Batch reactor temperature response with PI hybrid fuzzy controller

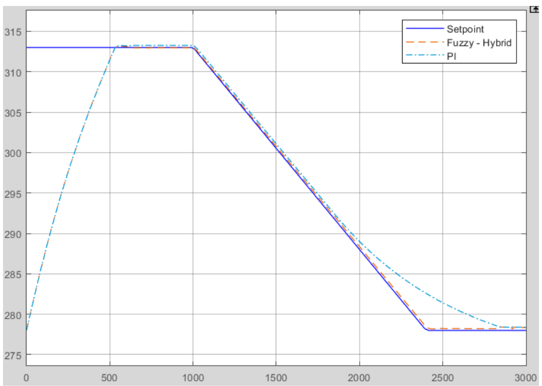

Figure 18: Comparison of the quality of the PI controller and the PI hybrid fuzzy controller

Figure 17, Figure 18 shows that the PI hybrid fuzzy controller has good control quality at both phases (Figure 19): static error is zero, the temperature at the end of the reaction is 278K as required design. Meanwhile, the quality of the PI controller still has a big deviation.

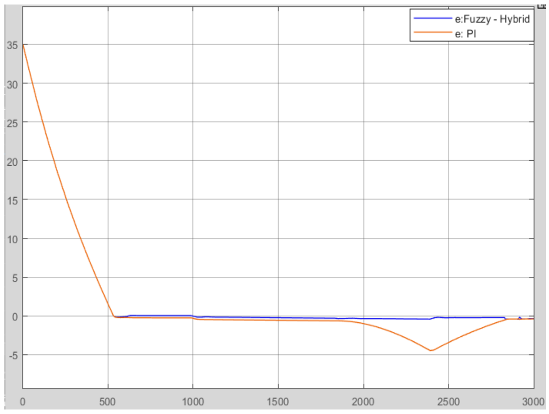

Figure 19: Comparison of control deviation of controllers

IV. CONCLUSIONS

The paper has studied the batch reactor kinetics and the acetic Anhydride hydrolysis reaction process and has built object simulation models on Matlab-Simuink. The PI controller design and the PI hybrid fuzzy controller control the temperature of the reactor in batches. The simulation results of the hybrid fuzzy controller give good control quality; the reactor's temperature response adheres to the set temperature at both phases: heating and cooling to ensure concentration, temperature according to technical requirements.

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