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Design of Controllers for Continuous Stirred Tank Reactor

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ABSTRACT

The objective of the project is to design various controllers for temperature control in Continuous Stirred Tank Reactor (CSTR) systems. Initially Zeigler-Nichols, modified Zeigler-Nichols, Tyreus-Luyben, Shen-Yu and IMC based method of tuned Proportional Integral (PI) controller is designed and comparisons are made with Fuzzy Logic Controller. Simulations are carried out and responses are obtained for the above controllers. Maximum peak overshoot, Settling time, Rise time, ISE, IAE are chosen as performance index. From the analysis it is found that the Fuzzy Logic Controller is a promising controller than the conventional controllers.

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1. INTRODUCTION

Process Industries play a significant role in economical growth of a nation. Most of the chemical process systems are nonlinear in nature. While there may be an extensive understanding of the behavior of nonlinear process, satisfactory methods for their control are still evolving.

Control of temperature is an important and common task in process industries. For example, consider the control of temperature in a boiler drum. Too high or too low temperature in the boiler drum can result in problems. It is important to maintain the temperature as close as possible to the required set point. The control of temperature in a CSTR is a challenging task, this is due to the relationship between controlled variable and the manipulated variable. The wide applications of temperature control of CSTR includes, the raw materials stock of the chemical works with certain temperature, and mixing the raw materials for process of the lithification works and the output products reaction of the biochemical technology. Most of the chemical industry, oil/gas production industries are widely uses the CSTR for the purpose of mixing the two or more reactants at certain temperature in the presence of catalyst to gives the chemical product of specified temperature.

There exists a variety of methods for temperature control. Very often a PID controller is used for temperature control in most application. An conventional PID controllers have limitation in nonlinear systems, complex and vague that have no precise mathematical model. To overcome these difficulties, a class of non conventional type of controller employing fuzzy logic has been designed and simulated for this purpose K.S. Tang (2001). Fuzzy logic controller is a promising controller in terms of percentage overshoot and system response in temperature control in face of nonlinearities introduced by pumps, valves and sensors.

The purpose of the project is to design a fuzzy logic controller (FLC) for temperature control. In recent years, fuzzy logic control has emerged as one of the principle areas of research in chemical process control. Fuzzy logic control is especially suitable for complex, ill-defined processes that do not lend themselves to control by conventional classical control strategies.

This paper attempts to use different method of tuned Proportional Integral (PI) controller is designed for a temperature control of CSTR.

This paper is organized as follows. Section II presents the mathematical modeling of CSTR. Section III presents the design of Fuzzy Logic Controller. Simulation results are discussed in section IV. Finally, section V concludes the paper.

2. CONTINUOUS STIRRED TANK REACTOR

Continuous Stirred Tank Reactor (CSTR), also known as vat- or Back mix reactor, is a common type of ideal reactor in chemical industry. CSTR is a complex nonlinear system. The Schematic of a CSTR is shown in Figure 1.

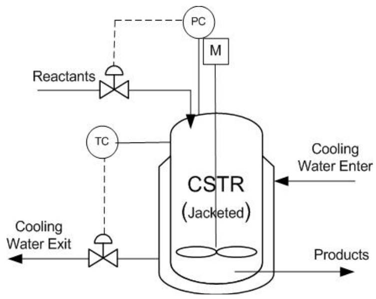

Figure 1. The Schematic of a CSTR

2.1. Mathematical Model for CSTR Process

A simple exothermic reaction A→B takes place in the reactor, which is in turn cooled by a coolant that flows through a jacket around the reactor.

The fundamental dependent quantities for the reactor are:

(a) Total mass of the reacting mixture in tank
(b) Mass of chemical A in the reacting mixture
(c) Total energy of the reacting mixture in the tank

In this process the heat produced due to the reaction is removed by a coolant medium that flows through a jacket around the reactor.

As known from the analysis of a CSTR system, the amount of heat released by the exothermic reaction is a non linear function of the temperature T inside the reactor.

On the other hand, the heat removed by the coolant is a linear function of the temperature T. When the CSTR is at steady state, heat produced by the reaction should be equal to the heat removed by the coolant Let us apply the conservation principle on the three fundamental quantities:

Total Mass Balance:

$$\frac{d(\rho V)}{dt} = \rho_i F_i - \rho F \pm 0 \tag{1}$$

Mass Balance on Component A:

$$\frac{d(n_A)}{dt} = \frac{d(c_A V)}{dt} = C_{A_i} F_i - C_A F - rV \tag{2}$$

Total Energy Balance:

$$E = U + K + P \tag{3}$$

Assume the reactor does not move (i.e., dK/dt = dP/dt = 0), the left-hand side of the total energy balance yields:

$$\frac{dE}{dt}=\frac{d(U+K+P)}{dt}=\frac{dU}{dt} \quad (4)$$

Since the system is a liquid system, we can make the following approximation:

$$\frac{dU}{dt}\cong\frac{dH}{dt} \quad (5)$$

Characterize Total Mass:

$$\frac{d(\rho V)}{dt}=\rho\frac{dV}{dt} \qquad \rho_i - \rho \quad (6)$$

Characterize the Mass of A:

$$\frac{dC_A}{dt}=\frac{F_i}{V}(C_{Ai}-C_A)-k_o e^{-E/RT}C_A \quad (7)$$

State variables:

$$V, C_A, T \quad (8)$$

State Equations:

$$\frac{dV}{dt}=F_i-F \quad (9)$$

$$\frac{dT}{dt}=\frac{F_i}{V}(T_i-T)+Jk_o e^{-E/RT}C_A-\frac{Q}{\rho C_p V} \quad (10)$$

$$\frac{dC_A}{dt}=\frac{F_i}{V}(C_{Ai}-C_A)-k_o e^{-E/RT}C_A \quad (11)$$

The Transfer Function Model of the CSTR is given as:

$$G(s)=\frac{-1.1170s+3.1472}{s^2+4.6429s+5.3821} \quad (12)$$

3. FUZZY LOGIC CONTROLLER DESIGN

Fuzzy logic control is derived from fuzzy set theory introduced by Lofti Zadeh in 1965. Fuzzy logic is a paradigm for an alternative design methodology, which can be applied in developing both linear and non-linear systems. It is realized that incorporating human intelligence into automatic control system would be a more efficient solution and this led to the development of the fuzzy control algorithms. Fuzzy control, which has its roots in fuzzy set development proposed by professor Zadeh, allows the experience and knowledge gained in previous systems for the control of processes. Fuzzy logic control is especially suitable for compensating non-linearities. The systematic property of fuzzy logic can convert the linguistic control rules based on expert knowledge into automatic control strategies. Such non-linear mathematical control algorithms can be implemented easily in the computer. They are straightforward and should not involve in any computational problems.

3.1. Fuzzification

Fuzzy logic uses linguistic variables instead of numeric variables. The process of converting a numerical variable in to a linguistic variable is called Fuzzification. In the present work the error and change in errors are taken as the inputs and the output. The error of range is converted in to seven linguistic values namely NB, NM, NS, ZR, PS, PM, PB. Similarly change in error of some range is converted to seven linguistic values. The controller output of some range is also converted in to linguistic values namely NB, NM, NS, ZR, PS, PM and PB. Triangular membership function is selected and the element of the each of the term sets are mapped on to the domain of corresponding linguistic variables.

3.2. Rule Base

Basically, the decision logic stage is similar to a rule base consists the fuzzy control rules to decide how FLC works. The stage is constructed by expert knowledge and experiences. The rules are generated heuristically from the response of the conventional controller. 49 rules derived from careful analysis of trend obtained from the simulation of conventional controller and known process knowledge. The decision making stage processes the input data and computes the controller outputs.

Table 1. Rule Table of Fuzzy Logic Controller

de / *e*	**NB**	**NM**	**NS**	**ZR**	**PS**	**PM**	**PB**
NB	NB	NB	NB	NM	NS	NS	ZR
NM	NS	NB	NM	NS	NS	ZR	PM
NS	NB	NM	NS	NS	ZR	PS	PM
ZR	NM	NM	NS	ZR	PS	PM	PB
PS	NM	NS	ZR	PS	PS	PM	PB
PM	NS	ZR	PS	PS	PM	PB	PB
PB	ZR	PS	PS	PM	PB	PB	PB

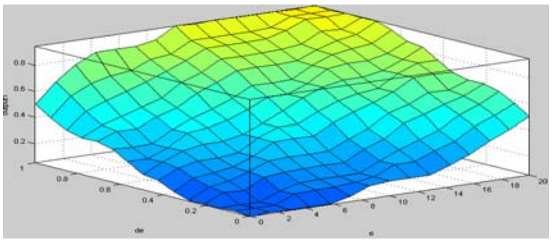

Figure 2. Surface View of Fuzzy Rules

3.3. Defuzzification

The output of the rule base is converted into crisp value, this task is done by defuzzification module. Centroid method of defuzzification is considered for this application. This is the process where the membership functions are sampled to find the grade of membership. Then the grade of membership is used in the fuzzy logic equations and outcome region is defined. The function of defuzzification module is to perform the defuzzification, which converts the set of modified output values in to a crisp value.

Table 2. Controller Gain Parameters for Temperature Control

PI Controller tuning method	K_p	T_i
Ziegler-Nichols	1.87	1.60
Modified Ziegler-Nichols	1.71	1.54
Tyreus-Luyben	1.29	1.45
Shen-Yu	1.38	1.56
IMC based PI	1.46	1.32

4. RESULTS AND DISCUSSION

The simulation results are given in this chapter. The set point tracking responses of CSTR using conventional PI controller and Fuzzy logic controller have been shown. The results of the ZN/MZN, Tyreus-Luyben, Shen-Yu and IMC Based tuned PI and Fuzzy Logic Controller are compared.

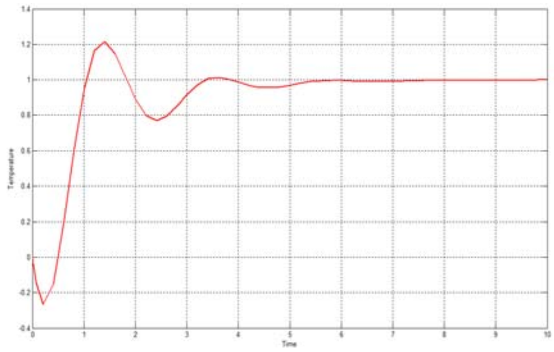

Figure 3. Set point tracking of CSTR process with ZN PI controller

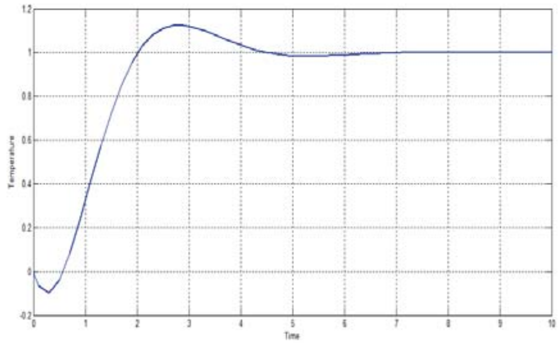

Figure 4. Set point tracking of CSTR process with MZN PI controller

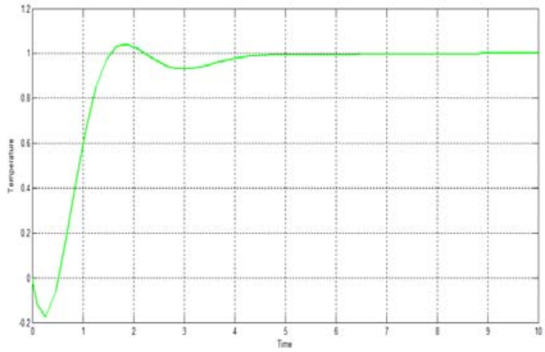

Figure 5. Set point tracking of CSTR process with Shen-Yu tuning PI controller

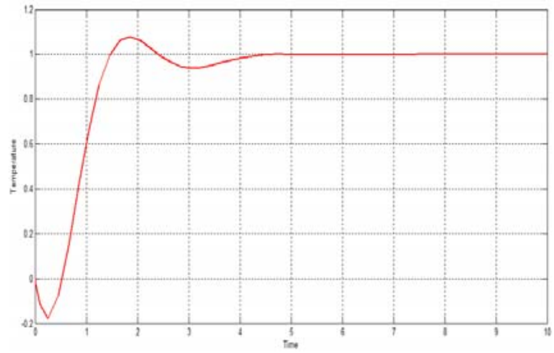

Figure 6. Set point tracking of CSTR process with Tyreus-Luyben tuning PI controller

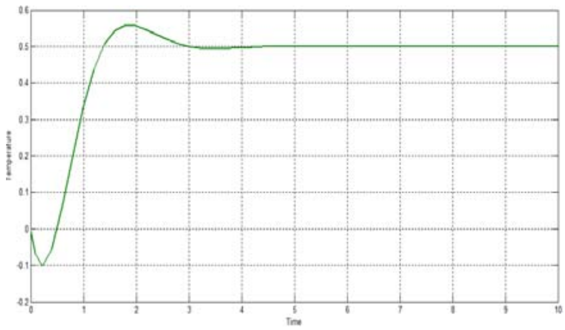

Figure 7. Set point tracking of CSTR process with IMC Based tuned PI controller

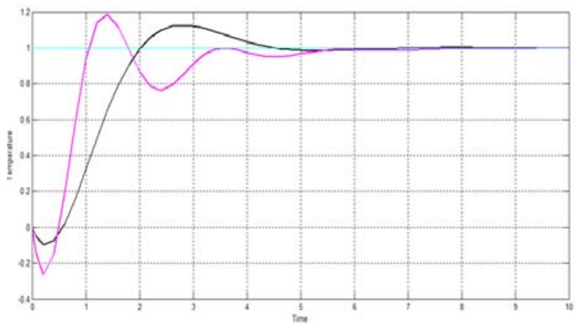

Figure 8. Comparison of ZN and MZN tuned PI controller

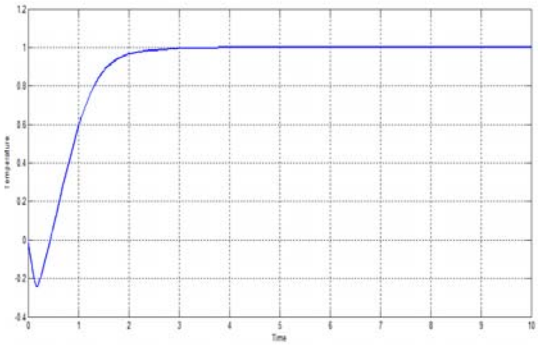

Figure 9. Fuzzy Logic Controller for CSTR

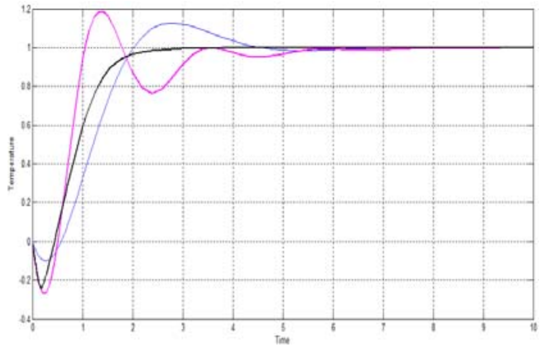

Figure 10. Comparison of ZN, MZN and Fuzzy logic controller

Table 3. Comparison of Transient Response Characteristics of CSTR

Controller	peak overshoot (M_p) in %	Ts in sec	Tr in sec
Ziegler-Nichols	18.9	8.2	0.98
Modified Ziegler-Nichols	16.2	6.8	1.7
Tyreus-Luyben	14.3	7.2	1.5
Shen-Yu	13.7	6.9	1.4
IMC based PI	13.2	6.3	1.2
FLC	-	5.8	3.2

Table 4. Quantitative Comparison using Performance Indices

Controller	ISE	IAE	ITAE
Ziegler-Nichols	1.593	1.981	10.52
Modified Ziegler-Nichols	1.334	1.664	6.561
Tyreus-Luyben	1.204	1.543	5.754
Shen-Yu	1.215	1.432	5.642
IMC based PI	1.113	1.345	5.861
FLC	0.945	1.367	4.382

Figures from Figure 3 to 10 shows the simulation results of ZN, MZN, Tyreus-Luyben, Shen-Yu and IMC based tuned PI Controller response for CSTR system is shown. As seen from the simulation results, PI-ZN Account for the largest amount of overshoot, but has a fast response. PI-MZN, Tyreus-Luyben, Shen-Yu has a relatively less percentage overshoot whereas the fuzzy logic controller results in no overshoot. The MATLAB simulation of PI-ZN, PI-MZN, PI-Tyreus-Luyben, Shen-Yu and Fuzzy logic controller. Thus we see there is a tradeoff between percentage overshoot and system response. From these results it is again said that Fuzzy logic controller is a promising controller in temperature control in reactor.

5. CONCLUSION

This paper presents temperature control in Continuous Stirred Tank Reactor [1] Fuzzy logic control is especially suitable for complex systems. The fuzzy based controllers are useful when precise mathematical formulations are infeasible. In conventional PI controllers tuning methods has moderate transient response characteristics and performance index. Fuzzy logic controller has the better response and performance indices than conventional PI controller tuning method. From the analysis it can be concluded that Fuzzy Logic Controller is a promising controller in process industries.

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