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Fuzzy Based Temperature Controller For Continuous Stirred Tank Reactor

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ABSTRACT: Fuzzy based PID controller is implemented to control the reactant temperature of a continuous stirred tank reactor(CSTR). The plant is modeled mathematically for the normal operating condition of CSTR. Then the transfer function model is obtained from the process. The analysis is made for the given process for the design of controller with conventional PID (trial and error method), Ziegler Nichols method and Fuzzy logic method. The servo response is obtained for all the above three methods and traced different operating condition of temperatures. The servo response of Fuzzy based PID controller has given better setpoint tracking capability than the Ziegler-Nichols method and conventional PID method.

Keywords: CSTR, Conventional PID-Controller, Ziegler-Nichols PID-Controller, Fuzzy PID-Controller.

I. INTRODUCTION

The continuous stirred-tank reactor (CSTR), also known as vat- or back mix reactor, is a common ideal reactor type in chemical engineering. Chemical kinetics and reactor design are at the heart of producing almost all industrial chemicals. The selection of a reaction system that operates in the safest and most efficient manner can be the key to the success or failure of a chemical plant. The reaction occurred in a reactor is exothermic or endothermic.

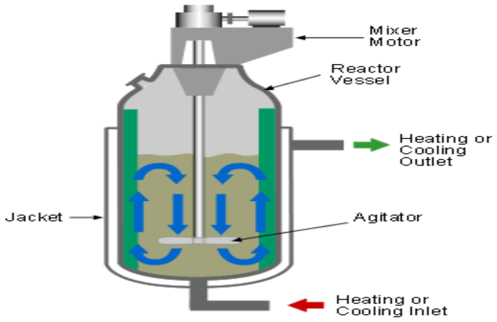

Fig. 1 Continuous Stirred Tank Reactor

The reactor is generally assembled with a jacket or coil in order to maintain the reaction temperature in the reactor. If heat is evolved due to exothermic reaction, a Coolant stream is required to pass through the jacket or coil to remove the extra heat. On the other hand, if endothermic reaction occurs in the system, the flow of heating medium is passing through jacket or coil for maintain the reaction temperature. A reactor operates at a constant temperature, then that is called as the isothermal reactor. If any exothermic or endothermic reactions are involved in the reactor, the temperature of the reactions mixture varies with time and we need to develop the energy balance equation for this non-isothermal reactor.

A. *Servo Operation*

The purpose of the control system is to make the process follow changes in the set point as closely as possible, such an operation is called servo operation. Changes in load variables such as uncontrolled flows, temperature and pressure cause large errors than the set point changes (normally in batch processes). In such cases servo operation is necessary. Though the set point changes quite slowly and steadily, the errors from load changes may be as large as the errors caused by the change of set point. The CSTR also has the problem like above. In such cases also servo operation may be considered. In this case the objective is to force some parameter to vary in a specific manner. This may be called ‘a tracking control system’ or ‘a following control system’.

II. MATHEMATICAL MODELLING FOR CSTR

The component balance equation is

$$\begin{bmatrix}\text{Rate of accumulation}\\ \text{within the system}\end{bmatrix}=\begin{bmatrix}\text{Rate of flow}\\ \text{into the system}\end{bmatrix}+\begin{bmatrix}\text{Rate of flow}\\ \text{out of the system}\end{bmatrix}+\begin{bmatrix}\text{rate of heat}\\ \text{generation by the}\\ \text{chemical reaction}\\ \text{within the system}\end{bmatrix} \tag{2.1}$$

Mass and energy balance equation of CSTR

$$\frac{dC_A(t)}{dt}=\frac{q(t)}{V}(C_{AO}(t)-C_A(t))-K_o e^{(\frac{-E}{RT(t)})}C_A(t) \tag{2.2}$$

$$\frac{dT(t)}{dt}=\frac{q(t)}{V}(T_o(t)-T(t))-((-\Delta H)K_o C_A(t)e^{(\frac{-E}{RT(t)})})+\frac{\rho_c c_{pc}}{\rho c_p V}q_c(t)\left\{1-e^{\frac{-hA}{q_c(t)\rho t_p}}\right\}(T_{co}(t)-T(t)) \tag{2.3}$$

The mass and energy balance equation of the CSTR as in ([5],[6]).
Where,

$C_A(t)$- Measured Product Concentration in mol/lit

$T(t)$- Reactor Temperature in Kelvin

at steady state,

$$\frac{dC_A(t)}{dt}=0 \quad \frac{dT(t)}{dt}=0$$

$$f_1(C_A,T)=0=\frac{q(t)}{V}(C_{AO}(t)-C_A(t))-K_o e^{(\frac{-E}{RT(t)})}C_A(t) \tag{2.4}$$

$$f_2(C_A,T)=0=\frac{q(t)}{V}(T_o(t)-T(t))-((-\Delta H)K_o C_A(t)e^{(\frac{-E}{RT(t)})})+\frac{\rho_c c_{pc}}{\rho c_p V}q_c(t)\left\{1-e^{\frac{-hA}{q_c(t)\rho t_p}}\right\}(T_{co}(t)-T(t)) \tag{2.5}$$

A. State Space Model of CSTR

The general state space model is following that,

$$\dot{x} = Ax + Bu$$
$$y = Cx + D$$

Where,

u= q_c (t) Coolant flow rate L/min.

$$\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} C_A \\ T \end{bmatrix} \qquad \dot{X} = \begin{bmatrix} \frac{\partial f_1}{\partial x_1} & \frac{\partial f_1}{\partial x_2} \\ \frac{\partial f_2}{\partial x_1} & \frac{\partial f_2}{\partial x_2} \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} + \begin{bmatrix} \partial f_1/\partial u \\ \partial f_2/\partial u \end{bmatrix} [u] \tag{2.6}$$

TABLE I
NORMAL OPERATING CONDITION OF CSTR

Sl. No	Process variable	Normal operating condition
1.	Concentration(CA)	0.0885 mol/lit
2.	Reactor Temperature(T)	441.1475 K
3.	Volumetric Flow Rate(q)	100 L/min
4.	Reactor Volume(V)	100l
5.	Feed Concentration(CAf)	1 mol/Lit
6.	Feed Temperature(Tf)	350 K
7.	Coolant Temperature(Tcf)	350 K
8.	Coolant Flow Rate(qc)	97 L/min
9.	Heat of Reaction(ΔH)	2e5 cal/mol
10.	Reaction Rate Constant(Ko)	7.2e10 /min
11.	Activation Energy term(E/R)	9980 K
12.	Heat Transfer term(hA)	7e5 cal/(min*K)

Calculating A, B, C, D matrix values as follows,

$$A = \begin{bmatrix} -12.1455 & -0.04692 \\ -2229.1 & -9.3856 \end{bmatrix} \quad B = \begin{bmatrix} 0 & 1.5033 \end{bmatrix} \quad C = \begin{bmatrix} 0 & 1 \end{bmatrix} \quad D = 0$$

Calculation for finding Transfer function

For q_c = 97 L/min.
C_A = 0.08235mol/Lit.
T = 443.4566 K

By using above values we get,

$$K_2 = 11.586$$
$$K_2' = 0.5891$$

The system transfer function,

$$G(s) = \frac{1.503s + 18.26}{s^2 + 21.53s + 9.403} \tag{2.7}$$

TABLE III
TRANSFER FUNCTION FOR DIFFERENT OPERATING POINTS

Sl. No	Qc(lit/min)	CA(mol/lit)	Temperature(K)	Transfer function
1.	97	0.0795	443.4566	$\text{System1} = \frac{1.414s + 18.51}{s^2 + 22.87s + 9.497}$
2.	100	0.0885	441.1475	$\text{System2} = \frac{1.492s + 17.57}{s^2 + 21.55s + 9.782}$
3.	103	0.0989	438.7763	$\text{System3} = \frac{1.582s + 16.71}{s^2 + 20.34s + 10.22}$
4.	106	0.1110	436.3091	$\text{System4} = \frac{1.681s + 15.87}{s^2 + 19.2s + 10.36}$
5.	109	0.1254	433.6921	$\text{System5} = \frac{1.788s + 15}{s^2 + 18.11s + 10.62}$

III. CONTROLLER DESIGN

A. *Conventional PID-Controller*

The trial and error tuning method is based on guess-and-check. In this method, the proportional action is the main control, while the integral and derivative actions refine it. The controller gain, K_c, is adjusted with the integral and derivative actions held at a minimum, until a desired output is obtained. The following tuning rule present in book titled "The Michigan chemical process dynamics and controls open text book" by prof. Peter Woolf, 2007**.**

TABLE IIIII
TRIAL AND ERROR METHOD TUNING RULE

S. No	Gains	Temperature process
1.	Kp	2-10
2.	ki	2-10
3.	kd	0-5

The trial and error tuning method is based on guess-and-check. The controller parameters are taken from Table III.

Kp=8; Ki=3; kd=1

From Table II, Transfer function as,

$$G(S)_2 = \frac{1.492s + 17.57}{s^2 + 21.55s + 9.782} \qquad (3.1)$$

B. *Ziegler-Nichols PID-Controller*

A proportional-integral-derivative controller (PID controller) is a generic control loop feedback mechanism (controller) widely used in industrial control systems. PID controller- proportional-integral-derivative controller.

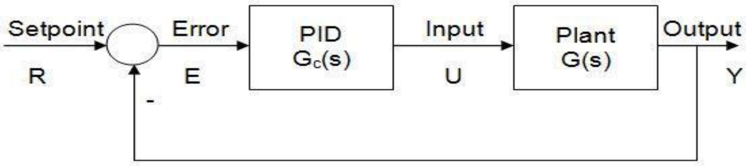

Fig. 2 Block diagram of PID controller with G(S) Plant

$$u(t)=K_P e(t)+K_i\int_0^t e(t)dt+K_d\frac{d}{dt}e(t) \tag{3.2}$$

Where,

Kp = Proportional gain
Ti = 1/Ki = integral gain
Td = 1/Kd = derivative gain
E = error = set point-process variable

The Ziegler–Nichols tuning method is a heuristic method of tuning a PID controller as in [3]. It was developed by John G. Ziegler and Nathaniel B. Nichols. Ziegler-Nichols tuning rule was the first such effort to provide a practical approach to tune a PID controller. Z–N tuning creates a "quarter wave decay". This is an acceptable result for some purposes, but not optimal for all applications.

TABLE IVV
ZIEGLER NICHOLS TUNING RULE

Sl. No	**controller**	**Kc**	**Ti**	**Td**
1.	P	Ku/2	-	-
2.	PI	Ku/2.2	Pu/1.2	-
3.	PID	Ku/1.7	Pu/2	Pu/8

TABLE V
CONTROLLER PARAMETERS FOR DIFFERENT OPERATING TEMPERATURES

S. No	At T=443.4566		At T=441.1475		At T=438.776		At T=436.3091		At T=433.692	
	Ku=1.3153 Pu=6.2724		Ku=1.3393 Pu=6.1683		Ku=1.3714 Pu=6.0460		Ku=1.3941 Pu= 5.9537		Ku=1.4312 Pu=5.8413	
	Controller	Gain values	Controller	Gain values	Controller	Gain values	Controller	Gain values	Controller	Gain values
1.	P	Kc=0.657	P	Kc=0.669	P	Kc=0.68	P	Kc=0.69	P	Kc=0.715
2.	PI	Kc=0.597 Ti=5.229	PI	Kc=0.608 Ti=5.142	PI	Kc=0.62 Ti=5.04	PI	Kc=0.63 Ti=4.96	PI	Kc=0.650 Ti=4.870
3.	PID	Kc=0.773 Ti=3.137 TD=0.784	PID	Kc=0.787 Ti=3.085 TD=0.771	PID	Kc=0.80 Ti=3.02 TD=0.7	PID	Kc=0.82 Ti=2.97 TD=0.7	PID	Kc=0.841 Ti=2.922 TD=0.730

C. Fuzzy PID-Controller

Fuzzy logic control is an efficient control for problems which are nonlinear and has scarce knowledge regarding them. Fuzzy inference system is a popular computing technique. Fuzzy is basically rule base methodology for computing different tasks. Here fuzzy is used to compute the gain values of the PID controller. The input to the fuzzy tuned controller is the error and change in error and the outputs are the PID gain values. The membership function used is a triangular membership function and defuzzification method used is centroid

Advantages of Fuzzy Logic Controller over Ziegler Nichols Controller,

1. Fuzzy PID Controller used for Non-Linear process.
2. Here dynamic behaviour of the process can be captured.
3. Process output meet the desired set point quickly.

D. DESIGN PROCEDURE OF FUZZY LOGIC PID CONTROLLER

1.Build and tune a conventional PID controller first.
2.Replace it with an equivalent linear fuzzy controller.
3.Make the fuzzy controller nonlinear.
4.Fine-tune the fuzzy controller

TABLE VI
FUZZY LOGIC CONTROLLER TUNING RULE

Sl.No	Controller	Kp	1/Ti	Td
1.	Fuzzy P	GE*GU	_	_
2.	Fuzzy PI	GCE*GU	_	GCE/GE
3.	Fuzzy PID	GE*GU	GIE/GE	GCE/GE

The controller parameters are tuned by fuzzy logic technique as in ([1],[3],[8]).

TABLE VII
FUZZY LOGIC RULES

E	EC K_P K_I K_D	NB	NM	NS	ZO	PS	PM	PB
NB		PB	PB	PM	PM	PS	PS	ZO
		NB	NB	NB	NM	NM	ZO	ZO
		PS	PS	ZO	ZO	ZO	PB	PB
NM		PB	PB	PM	PM	PS	ZO	ZO
		NB	NB	NM	NM	NS	ZO	ZO
		NS	NS	NS	NS	ZO	NS	NM
NS		PM	PM	PM	PS	ZO	NS	NM
		NM	NM	NS	NS	ZO	PS	PS
		NB	NB	NM	NS	ZO	PS	PM
ZO		PM	PS	PS	ZO	NS	NM	NM
		NM	NS	NS	ZO	PS	PS	PM
		NB	NM	NM	NS	ZO	PS	PM
PS		PS	PS	ZO	NS	NS	NM	NM
		NS	NS	ZO	PS	PS	PM	PM
		NB	NM	NS	NS	ZO	PS	PS
PM		ZO	ZO	NS	NM	NM	NM	NB
		ZO	ZO	PS	PM	PM	PB	PB
		NM	NS	NS	NS	ZO	PS	PS
PB		ZO	NS	NS	NM	NM	NB	NB
		ZO	ZO	PS	PM	PB	PB	PB
		PS	ZO	ZO	ZO	ZO	PB	PB

IV. SIMULATION AND RESULTS

The system was modelled and simulated using Matlab/Simulink. The simulated results of the system control with closed loop method and Conventional Controller and Z-N PID-Controller and Fuzzy PID-Controller were analysed.
fig 3, shows the Simulink block diagram of the closed loop systems.

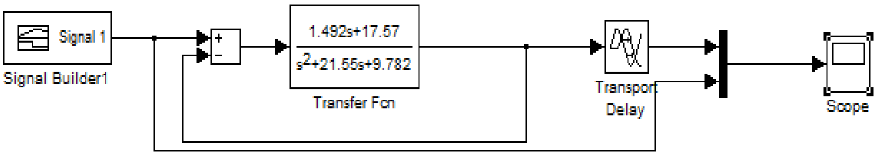

Fig. 3 Simulink Block Diagram for Closed loop systems

fig 4, shows the Simulink block diagram of Ziegler-Nichols PID-Controller.

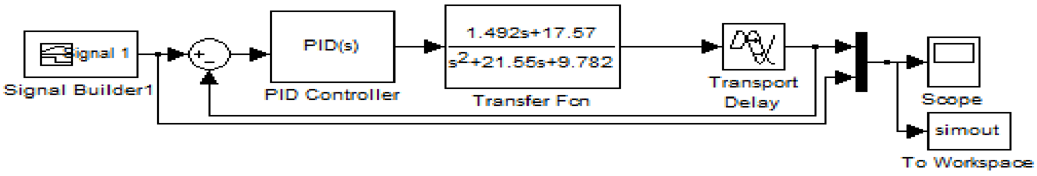

Fig. 4 Simulink Block Diagram for PID-Controller

fig 5, shows the Simulink block diagram of fuzzy PID-Controller

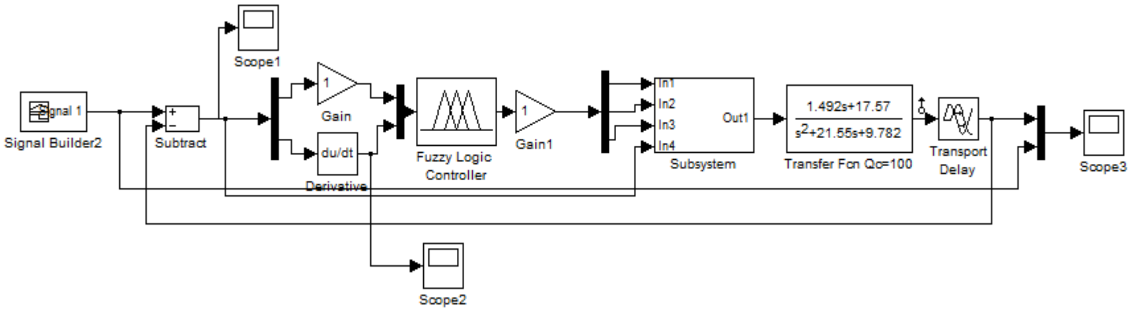

Fig. 5 Simulink Block Diagram for Fuzzy PID-Controller

The following fig 6, shows the servo response of closed loop system, the process output doesn't meet the desired set point.

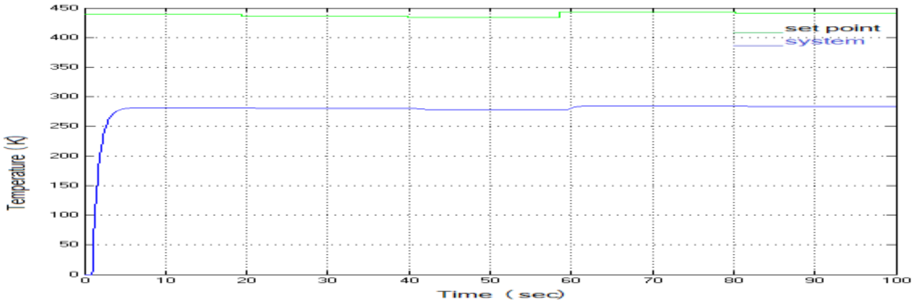

Fig. 6 Servo Response of Closed loop Systems

The following fig 7, shows the servo response of Trial and Error Method, the process output meet the desired set point quickly. The Controller parameters are Kp=8; Ki=3; kd=1 as in TABLE III. For simulation purpose equation (3.1) was used.

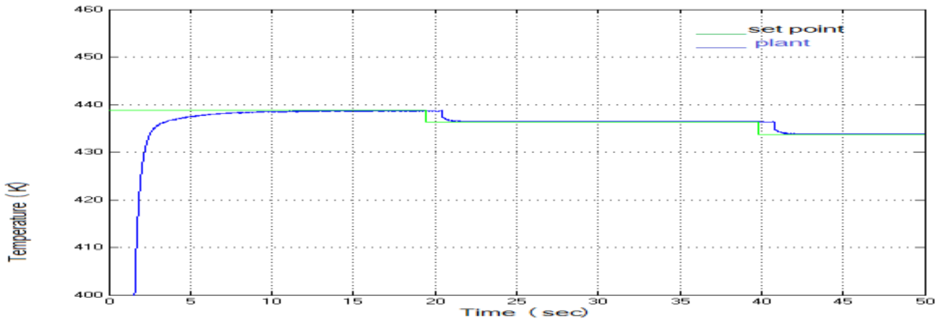

Fig. 7 Servo Response of Trial and Error Method

The following fig 8, shows the servo response of Ziegler-Nichols PID-Controller and Fuzzy PID-Controller, In the Fuzzy PID-Controller, The process output meet the desired set point quickly with less oscillation than the Ziegler-Nichols PID-Controller. The Controller parameters are Kp=0.7878; Ki=3.0857; kd=0.7714 as in TABLE V. For simulation purpose equation (3.1) was used.

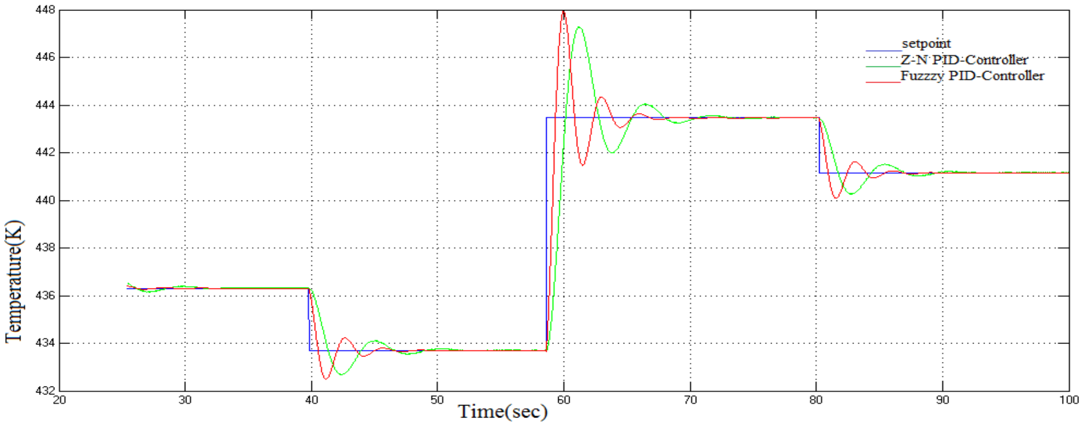

Fig. 8 Servo Response Comparison of Ziegler-Nichols PID-Controller and Fuzzy PID-Controller

V. CONCLUSION

The mathematical modelling of the process is done for all five operating conditions. Both the ZN-PID controller and Fuzzy based PID are able to maintain the set point at the desired value. However, the performances of Fuzzy based PID controller at all operating points are found to be better than ZN-PID, as there is less overshoot and settles to the set point faster. The Fuzzy based PID controller provides performance comparable to that of ZN-PID controller. The servo response based on Fuzzy PID controller meet the desired set point but small overshoot present in it. Hence in future an adaptive Particle Swarm Optimization (PSO) is to be used for the CSTR process for better controller tuning and proper set point tracking.

REFERENCES

[1] Chuen Chien LEE, “Fuzzy Logic in Control Systems: Fuzzy Logic Controller,” in IEEE Transactions on Systems, Man and Cybernetics, vol. 20, 1990.

[2] A. Conradie, R. Miikkulainen, and C. Aldrich, “Adaptive Control Utilizing Neural Swarming,” In Proceedings of the Genetic and Evolutionary Computation Conference, USA, 2002.

[3] J. Prakash, “Design of observer based nonlinear model predictive Controller for a continuous stirred tank reactor,” in Journal of Process control vol. 18 (2008) pp.504-514, 2008.

[4] M. Thangaraj, R. Abraham, “Particle swarm optimization using adaptive mutation,” in Proc. 19th International Conference on Database and Expert Systems Application, pp. 519-523, 2008

[5] J. Prakash, “Design of nonlinear PID controller and non-linear model predictive controller for a continuous stirred tank reactor,” in proceedings ISA Transactions 48, pp.273-282, 2009.

[6] M. Santos, S, Dormido, “Fuzzy-PID controllers vs. Fuzzy-PI controllers,” in IEEE Transactions Systems, Man and Cybernetics, vol. 20, no. 2, pp.404-418, 2009.

[7] Essam Nathen and Khalid, A. Buragga, “Comparison between Conventional and Fuzzy Logic PID Controller for controlling DC motors,” in International Journal of Computer science, vol. 7, Issue 5, September 2010.

[8] D. Krishnaa, K. Suryanarayanab, G.R. Aparnab, “Tuning of PID Controllers for Unstable Continuous Stirred Tank Reactors,” proceedings in International Journal of Applied Science and Engineering. 10, pp.1-18, 2012.

[9] S. Morkos, H. Kamal, “Optimal Tuning of PID Controller using Adaptive Hybrid Particle Swarm Optimization Algorithm,” by, International Journal of Computers, Communications & Control, ISSN 1841-9836, vol. 7, no. 1, pp. 101-114, 2012.