Temperature Control of CSTR Using Fuzzy Logic Control and IMC Control

Aravind R Varma and Dr.V.O. Rejini

Abstract--- Fuzzy logic controllers are useful in chemical processes where non-linearity is very high. Fuzzy based PID controller is used in improving the robustness of the system and to improve the noise rejection capability. Internal model controllers are useful in chemical processes where accurate model is not available. Internal model controllers need controller transfer function which can be calculated by determining inverse of process transfer function. By using internal model control settling time can be reduced when compared to PI or PID control. Continuous stirred tank heater with a recirculating jacket has more interacting dynamic behavior than classical CSTR. The jacket temperature is controlled by manipulating the inlet temperature.

Keywords--- Fuzzy Logic Control, Internal Model Control, CSTR, Mathematical Model, State Variable Form

I. INTRODUCTION

Chemical processes usually introduce high non-linearity and the parameters of these processes are time variant in nature. The dead time introduced by these processes is considerable. In these cases where non-linearity is high conventional controllers can be replaced by Fuzzy logic controllers. In fuzzy logic control precise knowledge about the system is not required. Rules developed are approximate in nature rather than exact.

It emulates the ability to reason and uses approximate data to find solution. Fuzzy logic control is a knowledge based control that works on the rules that are created based on the knowledge of experts. “If-Then” principle is used for the creation of rules.

Advantages of using fuzzy logic are the control system can be made robust as it doesn’t require precise, noise free inputs. Failure of system components doesn’t cause system to fail. Flexibility of the system is another feature that helps in modifying the rules.

Fuzzy rules can be defined for any number of inputs and outputs. Complexity of defining rules increase with increase in number of inputs and It would be better to break the system into smaller parts are several small fuzzy logic modules can be created each with limited functionalities.

Fuzzy logic model can be used for non-linear functions of arbitrary complexity. Most commonly used membership functions are triangular, rectangular, trapezoidal membership functions. Each membership functions are provided with linguistic variables.

A wide variety of methods are used to design PID controllers based on process models. Analytical expression for controller parameters can be derived from process model. Internal model control was developed by Morrari and co-workers.

A process model and controller output is used to determine the actual response. The error in both responses is the input to the internal model. Modeling errors and unknown disturbances are not accounted for this model.

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IMC Design parameters are developed based on Morrari's calculation.IMC controller is based on inverse of the process rather than entire process.IMC methods are used to develop equivalent controllers when modeling errors and known disturbances are present.

Continuous flow reactors are always operated at steady state. There are 3 types of Continuous flow reactors. CSTRs, PFRs, Packed Bed Reactors. CSTRs are mainly used for liquid phase reactions. It is normally operated at steady state and is perfectly mixed. Temperature and concentration are independent of time and position. Temperature and concentration at exit stream is same as inside the CSTR.

II. PROCESS MODEL

The examined reactor has real background and graphical diagram of the CSTR reactor is shown in Figure 1. The mathematical model of this reactor comes from mass balance and energy balance inside the reactor. Notice that: a jacket surrounding the reactor also has feed stream and exit streams. The jacket is assumed to be perfectly mixed and at lower temperature than the reactor.

Energy passes from the reactor walls into jacket removing the heat generated by reaction. The control objective is to keep the temperature of the reacting mixture T, constant at desired value. The only manipulated variable is coolant temperature T_J.

$d C_A/ dt = 0, dT/dt = 0, dT_j/dt = 0$

$F_1 (C_A, T, T_j) = d C_A/ dt = 0$

$F_1 (C_A, T, T_j) = dT/dt = 0$

III. PI CONTROL OF THE PROCESS

$$P(t)= K_p e(t)+ K_p/T_I \int e(t) +P(0)$$

Propotional control action produces a control signal that is propotional to error signal. Integral action produces signal that accumulates present and past errors. Propotional action improves speed of response and Integral action improves

Settling time.

Table 1: Parameters of CSTR

Parameter	*Values*	*Unit*
Ea	32.400	Btu/lbmol
k_o	$16.96*10^{12}$	Hr^{-1}
U	75	$Btu/hrft^2\,°F$
ρc_p	53.25	$Btu/ft^3\,°F$
R	1.987	Btu/lbmol°F
F	340	Ft^3/hr
V	85	Ft^3
Ca_f	0.132	$Lbmol/ft^3$
T_f	60	°F

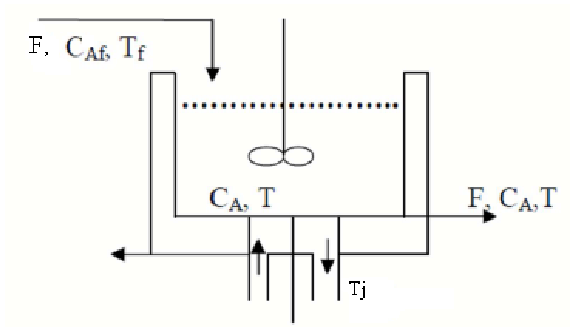

Fig. 1: CSTR with Cooling Jacket

The goal of the linearization procedure is to find a model with the form

$X' = Ax + Bu$ ……………………….(1)

$y = Cx + Du$ ……………………….(2)

Table 2: Tuning Parameters of PI Control

Controller	K_P	K_I
Proportional Integral	1.0	0.04

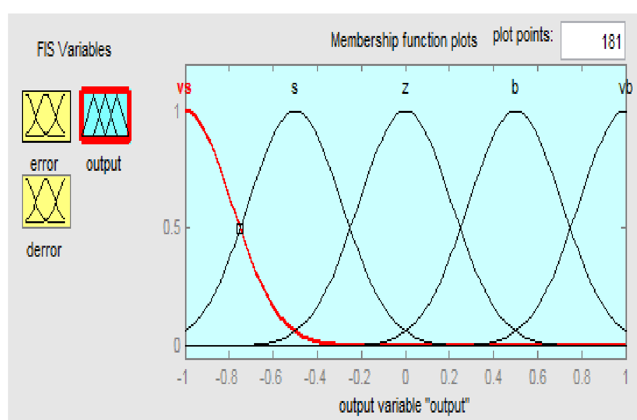

Fig. 2: Membership Function for Output

$$A = \begin{bmatrix} -7.9909 & -0.013674 \\ 2922.9 & 4.5564 \end{bmatrix}$$

$$B = \begin{bmatrix} 0 \\ 1.4582 \end{bmatrix}$$

$$C = \begin{bmatrix} 0 & 1 \end{bmatrix}$$

$$D = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

$$\frac{C(s)}{R(s)} = \frac{1.4582s + 11.65}{s^2 + 3.434s + 3.557}$$

IV. Fuzzy Logic Control

Fuzzy logic concept is used in controlling the temperature of a CSTR with cooling jacket. Gaussian membership functions are used with 5 linguistic variables. Linguistic variables are very small (vs), small(s),zero(z),big(b),very big (vb). These linguistic variables are used for error, change of error and output. Error and change of error varies from -6 to 3. Output varies from -1 to 1.

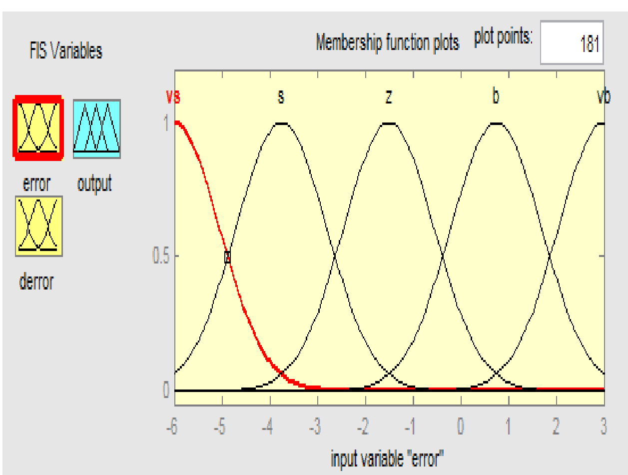

Fig. 3: Membership Function for Error

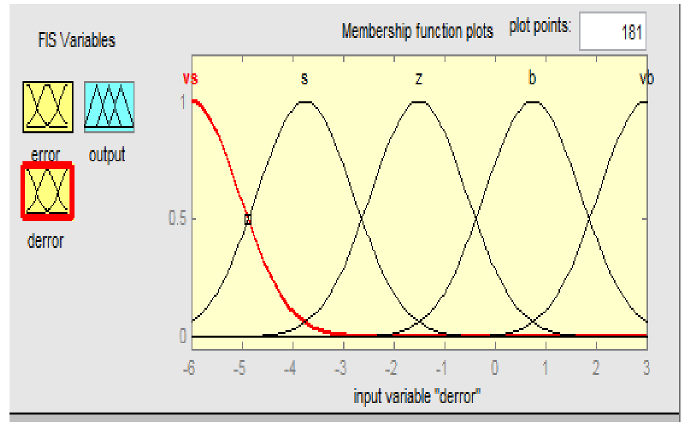

Fig. 4: Membership Function for Change of Error

Table 3: Fuzzy Rule Base

Error\derror	vs	s	z	b	vb
vs	vs	vs	vs	s	z
s	vs	vs	s	z	b
z	vs	s	z	b	vb
b	s	z	b	vb	vb
vb	z	b	vb	vb	vb

V. IMC Control

IMC Control parameters are determined based on Morrari's rules. For a second order system with a zero of the form TF= $(Bs+1)/(T^2s^2+2\delta Ts+1)$, tuning parameters of a PI Controller is given below.

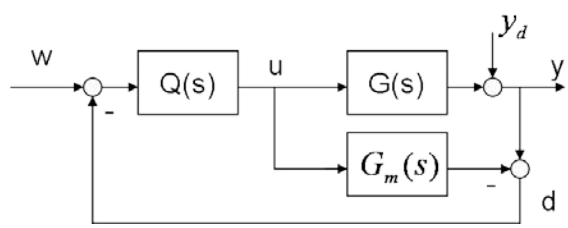

Fig. 5: Schematic of IMC Controller

Q is calculated by the relation $(1/(G_m(s)(\lambda s+1))$. Where lambda is the tuning parameter for the controller. Tuning parameter for two evaporators are 4 and 12 respectively for better response. When equivalent PID Controller is designed the relation $G_c = Q/(1-QG_m)$ is used.

$$G_m(s) = \frac{2.7s + 2.742}{s^2 + 1.33s + 0.4968}$$

$G_m(s)$ is determined from experimental data

Table 4: Tuning of IMC Controller

CONTROLLER	LAMBDA	K_p	K_I
IMC	0.5	0.368	0.14
IMC	1	0.184	0.07
IMC	2	0.092	0.035

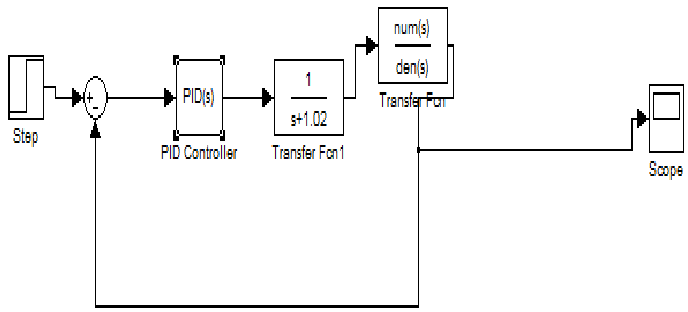

Fig. 5: Block Diagram of IMC Control

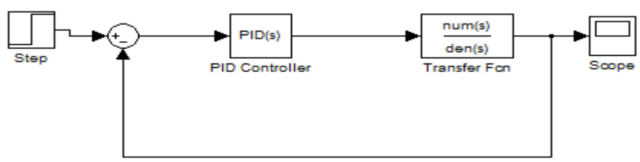

Fig. 6: Block Diagram of PI Control

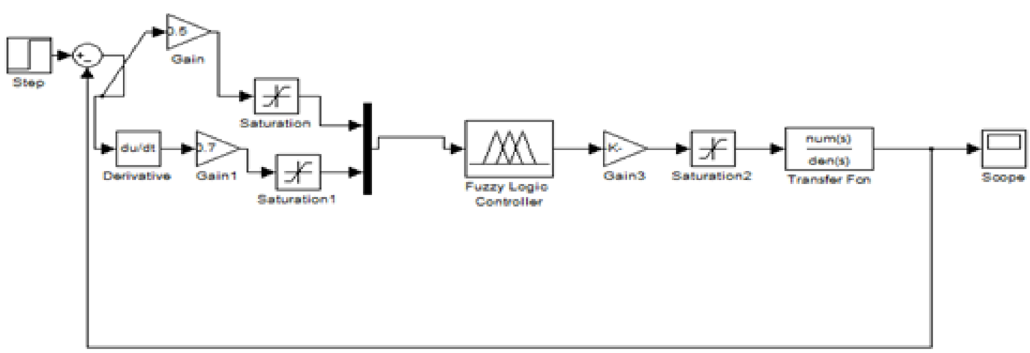

Fig. 7: Block Diagram of Fuzzy Control

VI. RESULTS

A unit step input is applied as set point and response is plotted for PI Control, IMC Control for 3 values of lambda and Fuzzy Control is obtained. Rise time, Settling time and overshoot for the different controllers are obtained.

Table 5: Result Analysis

CONTROLLER	RISE TIME(s)	SETTLING TIME(s)	OVERSHOOT (%)
PI	80	180	0
IMC (Lambda=0.5)	8	22	0
IMC (Lambda=1)	12	35	0
IMC (Lambda=2)	23	61	0
Fuzzy	1.8	3.7	0

VII. Conclusion

Rise time, settling time reduces as the value of lambda reduces in the case of IMC Controller. These values are very less for lambda=0.5. But the better response is provided by Fuzzy Logic Controller. As the value of lambda increases settling time and rise time increases but better than PI Controller.

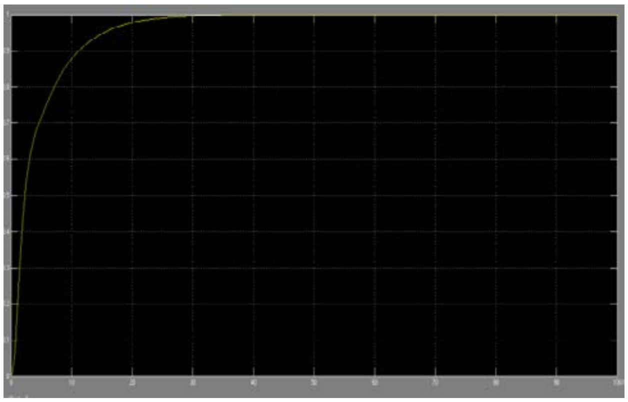

Fig. 8: IMC Control Response with Lambda=1

Fig. 9: IMC Control Response with Lambda=0.5

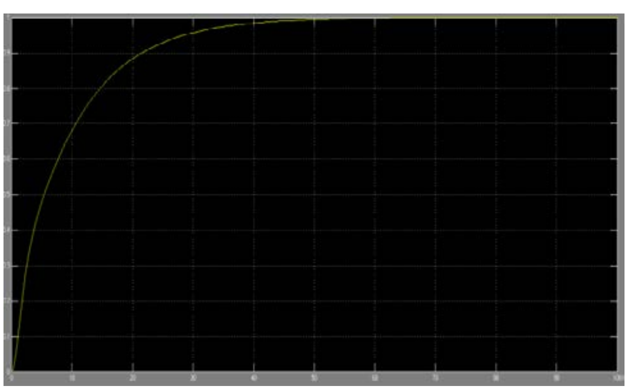

Fig. 10: IMC Control Response with Lambda=2

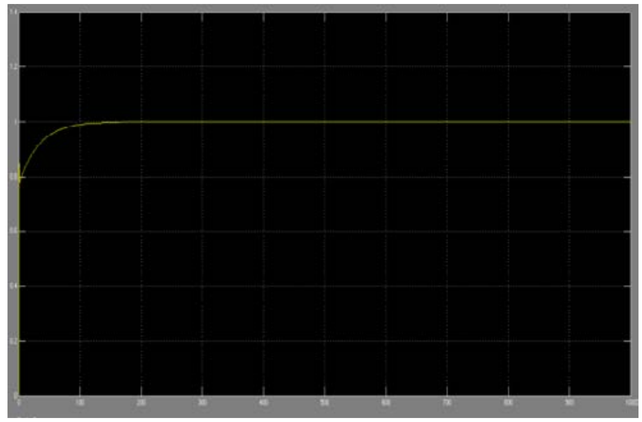

Fig. 11: PI Control Response

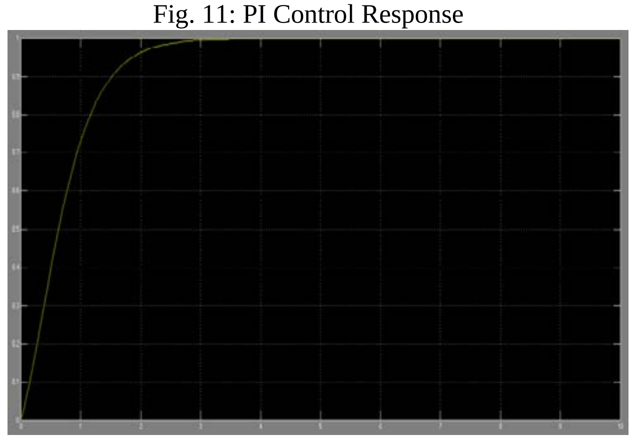

Fig. 12: Fuzzy Logic Control Response

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