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Comparative Analysis Of PID,Cascade and Fuzzy Logic Control For the Efficient Temperature control in CSTR

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Abstract:
Continuous Stirred Tank Reactor (CSTR) is an important topic in process control and offering a diverse range of researches in the area of the chemical and control engineering. This paper present three different control strategies PID control, Cascade control and Fuzzy logic control. The objective is to control the temperature of CSTR in presence of disturbance. Model design and simulation are done in MATLAB using Fuzzy logic tool box The temperature control is found better with Fuzzy logic control as compared to Cascade and PID control schemes respectively

Keywords: Fuzzy Logic (FL), PID Control, Temperature, Mamdani Fuzzy model, CSTR

1. INTRODUCTION

The problem of controlling the temperature of CSTR is considered as a challenging issue especially for a control engineer corresponding to its nonlinear dynamics. Most of the traditional controllers are restricted just for linear time invariant system application. But in real world, the nonlinear characteristics of system and their function parameter changes, due to wear and tear, that's why these changes can't be neglected. One of the most important controllers both in academic and industrial application is PID. PID controller has been applied in feedback loop mechanism and extensively used in industrial Process control since 1950s. Easy implementation of PID controller made it more popular in control system application. Basically PID tries to correct the error between measured outputs and desired outputs of the process in order to improve the transient and steady state response as much as possible.

In cascade control strategy, the output of the reactor temperature Controller is the set point for jacket inlet temperature. The output of the jacket temperature controller is the valve position for the coolant flow rate. The jacket recirculation flow rate is a bifurcation parameter that determines whether or not there is multiple steady-state behavior.

Fuzzy controlled system models don't require any certain model for implementation of system under consideration. Success of the fuzzy logic, which based on the approximate reasoning instead of crisp modeling assumption, remark the robustness of this method in real environment application. Fuzzy logic controller emulates the behavior of the expert in controlling system. Fuzzy logic doesn't need mathematical modeling which makes it more flexible in dealing with complex non linear problem. In this paper, CSTR has been used for the production of propylene Glycol by hydrolysis of propylene oxide with sulfuric acid as Catalyst. Water is supplied in access, so reaction is of first order.

Section 1 provides the introduction to the temperature control of CSTR using PID,cascade and fuzzy logic control techniques. Section II gives the mathematical modeling of CSTR for two state and three state models. SectionIII deals with simulation and results. Section IV concludes the paper and followed by the references.

II. Modeling of CSTR

The examined reactor has real background and graphical diagram of the CSTR reactor as shown in Figure 1. The mathematical model of this reactor comes from balances inside the reactor. Notice that a jacket surrounding the reactor also has feed and exit streams. The jacket is assumed to be perfectly mixed and at lower temperature than the reactor. Energy passes through 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 the coolant flow rate.

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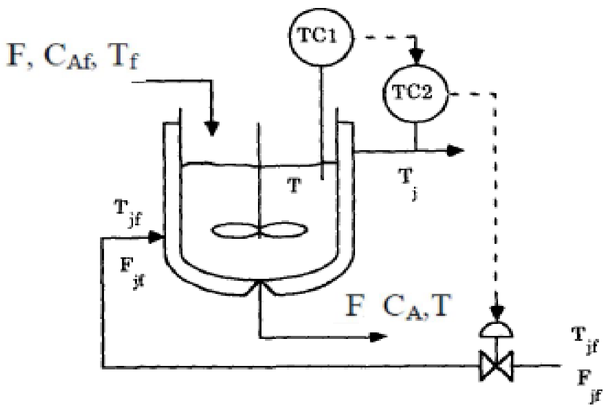

Figure1.Continues stirred tank reactor with cooling jacket

2.1. Steady State Solution

The steady state solution is obtained when dCA/dt= 0 ,dT/dt=0,dTj/dt=0 that is

$f_1(C_A,T,T_j)=dC_A/dt=0=F/V(C_{Af}-C_A)-K_o\exp(-E/RT)C_A$….(1.1)

$f_2(C_A,T,T_j)=dT/dt=0=F/V(T_f-T)+(-\Delta H/\rho C_P)K_0\exp(-E/RT)C_A)$ –

$UA/V\rho C_P(T-T_j)$……….(1.2)

$F_3(C_A,T,T_J)=$ $dT_j/dt=0=F_j/V_j(T_{jf}-T_j)+UA(T-T_j)/(V_J p_j c_{pj})$… ……………. (1.3)

Table for Reactor Parameter's value

Parameter	*Values*	*Unit*
Ea	32.400	Btu/lbmol
k_o	$16.96*10^{12}$	Hr^{-1}
U	75	Btu/hrft^2 ^{o}F
pc_p	53.25	Btu/ft^3 ^{o}F
R	1.987	Btu/lbmol^{o}F
F	340	Ft^3/hr
V	85	Ft^3
V_J/V	.25	-
T_{jf}	0	^{o}F
p_jc_{pj}	55.6	Btu/ft^{3o}F
Ca_f	0.132	Lbmol/ft^3
T_f	60	^{o}F

2.2 Linearization

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

$X' = Ax + Bu$ …………………….(1.4)

$y = Cx + Du$ …………………….(1.5)

Where the states, inputs and output are in deviation variable.

Using the parameters given in above table we can find the State space model for PID controller design

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

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

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

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

Hence transfer function for PID control will be (T/T_j)

$$G_P = \frac{1.458s+11.65}{s^2+3.434s+3.557} \quad \text{……… (1.6)}$$

Using all reactor parameter's value we can find the following State space model for cascade system

$$A = \begin{bmatrix} -79909 & -0.013674 & 0 \\ 2922.9 & 4.5564 & 1.4582 \\ 0 & 4.7482 & 5.8977 \end{bmatrix}$$

$$B = \begin{bmatrix} 0 \\ 0 \\ -3.2558 \end{bmatrix}$$

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

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

G_{P1} is the transfer function between (T/T_j)

$$G_{P1}=\frac{4.7476s+37.9377}{3.2558s^2+11.1820s+11.260}\quad\ldots\ldots\ldots\ldots(1.7)$$

G_{p2} is the transfer function between (T_j/F_j)

$$G_{P2}=\frac{-3.2558s^2-11.1820s-11.2606}{S^3+9.3322s^2+16.7904s+-34.9297}\quad\ldots\ldots\ldots\ldots(1.8)$$

The feed stream concentration is 0.132 lbmol/ft and an 50% conversion of propylene oxide has been determined to be reasonable. Since 50% of propylene oxide is converted to propylene glycol, the propylene glycol concentration is 0.066 lbmol/ft^3. In this process. it is seen that the process has inverse response with delay time as well as overshoot. To overcome this problem and to obtain the desired response, we are using PID control, Cascade control and Fuzzy Logic control. For that, the controller parameters are calculated. The desired parameters for the PID controller are the proportional

gain (K_P) integral gain (K_I) and the differential gain (K_D) can be calculated by the Automatic PID tuning method in MATLAB software or Ziegler Nichols tuning method.

Design specification for the set point tracking

1. Settling time under 5 second.
2. Peak overshoots less than 5%.
3. Steady state error equal to zero.

Design specification for disturbance rejection

1. Settling time under 5 second.
2. Peak deviation from steady state value less than 5%.

III. SIMULATION AND RESULTS

The operation of the CSTR is disturbed by external factors such as changes in the feed flow rate and temperature .we need to form a control action to alleviate the impact of the changing disturbances and to keep T only at the desired Set point. In this system the manipulated variable Fj is responsible to maintain the temperature T at the desired Set point. The reaction is exothermic and the heat generated is removed by the coolant, which flows in the jacket around the tank.

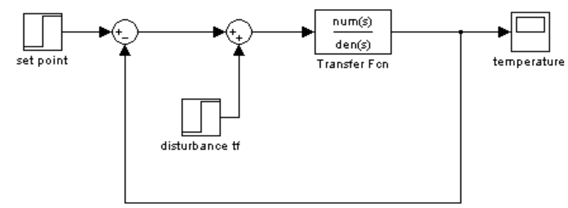

Figure2 Process model

Time response of uncontrolled process

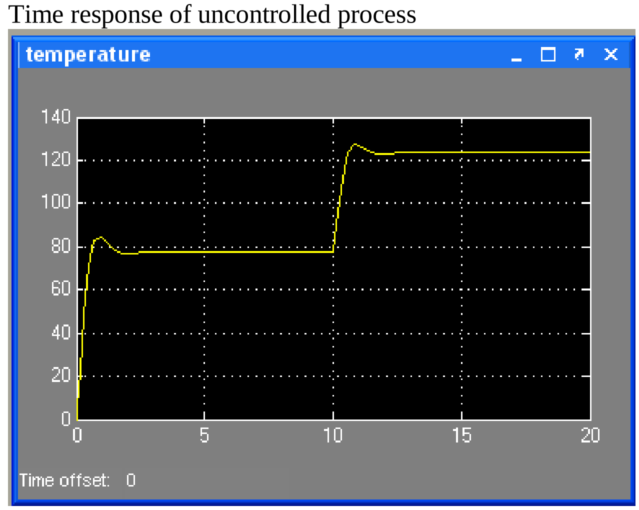

Figure 3.

As can be observed from the figure3 response of uncontrolled process produce high value of steady state error.

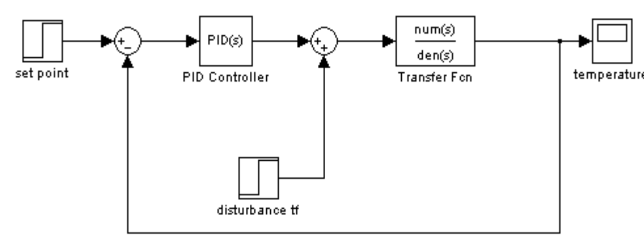

Figure4. CSTR with PID controller

Temperature output response

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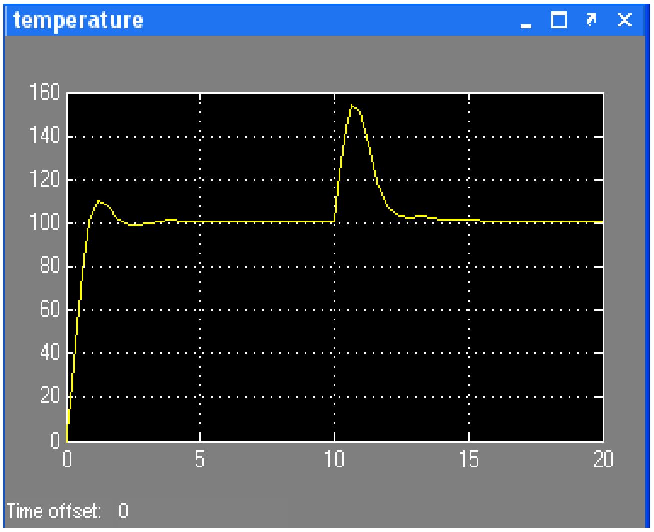

Figure5.
Response with PID controller

As can be observed from the figure5.

For set point tracking

Settling time (T_s) = 3 (sec)   Overshoot = 9%

Steady state error =0

For disturbance rejection

Settling time (T_s) = 4.4 (sec)   Peak deviation = 60%

In this case the operation of CSTR is perform by two PID Controller. One is primary controller for reactor process and Other is secondary controller for jacket process.

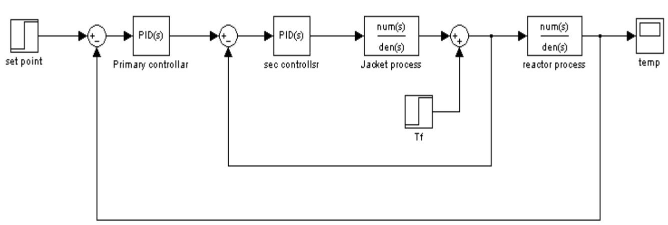

Figure6.Cascade control

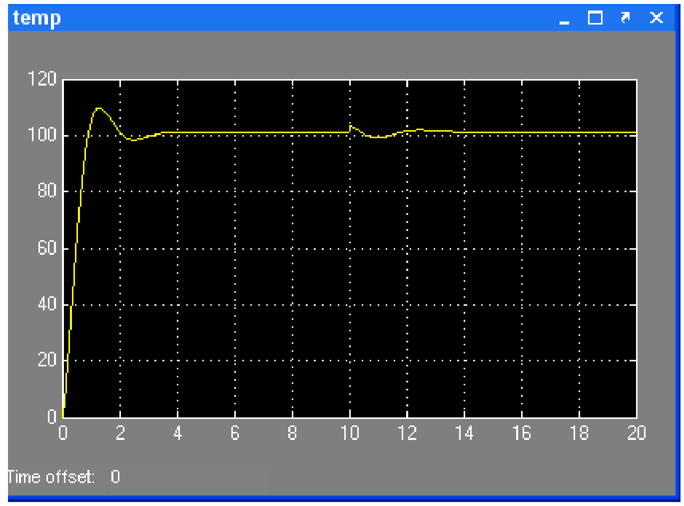

Figure7
Response with cascade control

As can be observed from the figure7,

For set point tracking

Settling time (T_s) = 3.8 (sec)   Overshoot = 9%

Steady state error =0

For disturbance rejection

Settling time (T_s) = 4.2(sec)   Peak deviation = 4%.

Fuzzy logic control design

In this case, the 50% of the ethylene oxide converted in to the ethylene glycol (output is 50% of the input). Thus the range for the output is [0 – 0.5]. The second input is error and its range is [0 – 0.5].Using these values, make fuzzy rules in the fuzzy rule base editor and observe the response that there is no inverted response, no overshoot, no undershoot, rise time and settling time are reduced to a negligible value from our response.

Membership values of input 1called error having three ranges low, medium and high is shown in figure 8.

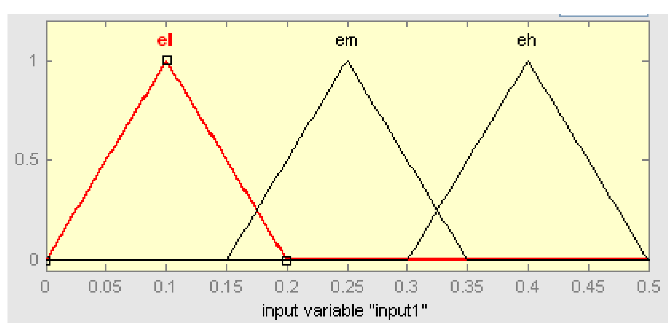

Figure 8 Fuzzy membership sets of input '1' (error**)**

In figure9.the membership values of input 2 called feedback having the three ranges low, medium and high:

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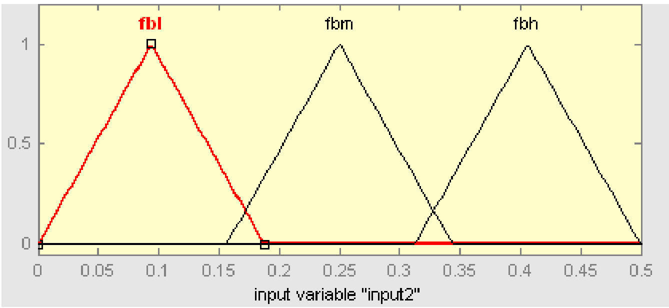
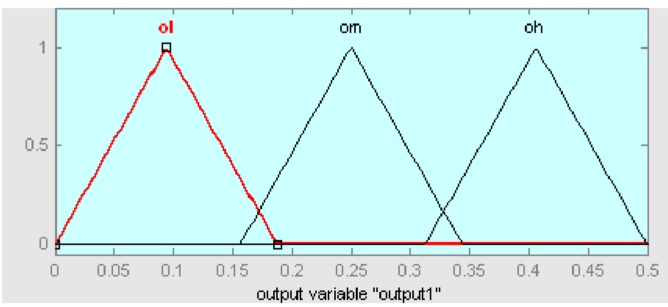


Figure9. Fuzzy membership sets of input ‘2’ (feedback)

In figure10.membership values of output having the same ranges low, medium and high.



Figore10. Fuzzy membership sets of output (output)

Fuzzy if-then rules using Mamdani fuzzy model are shown.

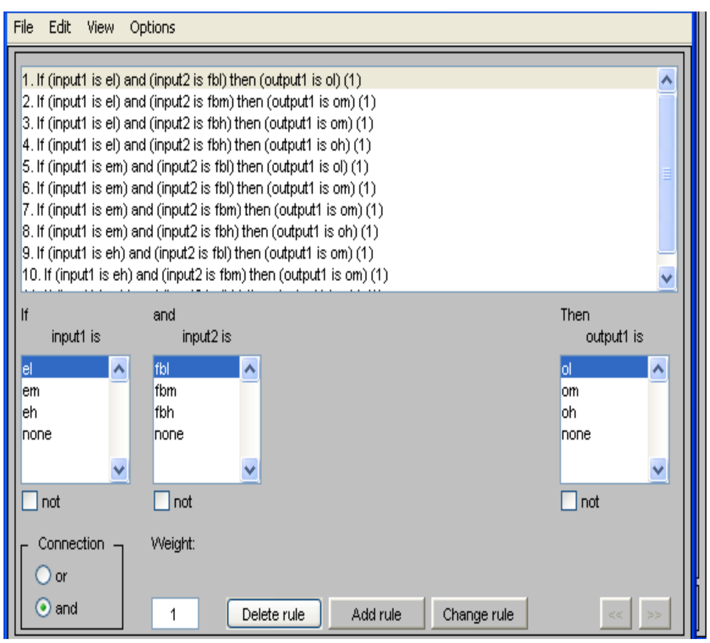


Figure11.

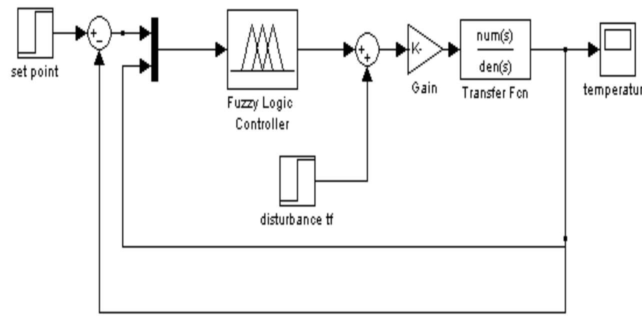


Figure12.CSTR with Fuzzy controller

Temperature output response of CSTR with fuzzy controller

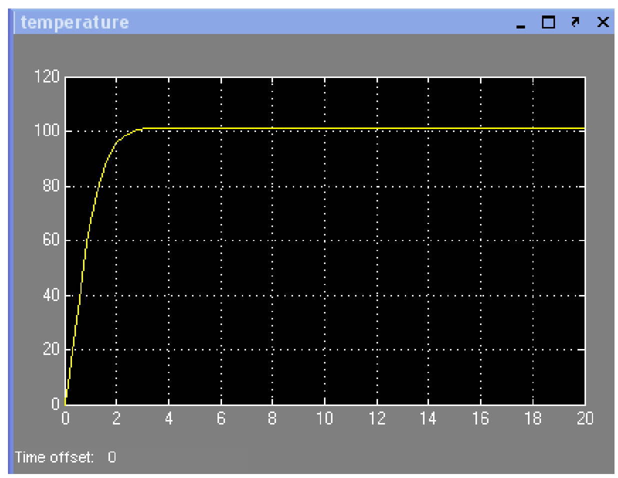


Figure 13

As can be seen from figure13

For set point tracking

Settling time (T_s) = 3.2(sec) Overshoot = 0 %

Steady state error = 0

For disturbance rejection

Settling time (T_s) = 0 (sec) Peak deviation = 0 %

IV. CONCLUSION

For set point tracking Settling time and Peak overshoot with PID control is 3(sec) and 9%. For disturbance rejection Settling time and Peak deviation with PID control is 4.4 (sec) and 60%. For set point tracking Settling time and Peak overshoot with Cascade control is 3.8(sec) and 9%. For disturbance rejection Settling time and Peak deviation with Cascade control is 3.7(sec) and 4%. For set point tracking

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Settling time and Peak overshoot with FLC is 3.2 (sec) and 0%. For disturbance rejection Settling time and Peak deviation with FLC is 0 (sec) and 0%. Thus Fuzzy controller provides the better settling time and peak overshoot value than other controller for disturbance rejection.

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