Performance Comparison and Analysis of a Designed Temperature Controller for a CSTR model

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Abstract- *This paper represents a novel design and control architecture of the continuous stirred tank reactor (CSTR) based on its mathematical equivalent modeling of the physical system. The plant is formed analytically 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 Convectional PID (trial and error method), Ziegler Nichols method, Fuzzy logic method and Model Reference Adaptive method. The simulation is done using MATLAB software and the output of above four different methods was compared so that the Model Reference Adaptive Controller has given better result. This thesis also compares the various time domain specifications of different controllers.*

Keywords- CSTR-PID-ZN-Fuzzy-MRAM-MATLAB.

I. INTRODUCTION

One of the most important and vital process in chemical industries is Continuous stirred tank reactor (CSTR). CSTR is a highly nonlinear system and its parameters affect its complex dynamic severely. Due to nesting and deactivation and regeneration of the stimulant the parameters of CSTR are varying with time. In addition, in the exothermal operating region of CSTR the dynamic behavior of this reactor is unsettled. So outline of a suited controller for such CSTR systems is rather complicated and requires more efforts. Various methods have been developed to control the CSTR system. Generally, three strategies of control such as feedback control, feed forward control and cascade control have been significantly used in process industries. Here designing feedback control using the controller with convectional PID, Ziegler Nichols method, Fuzzy Logic method, Model Reference Adaptive method. Then servo response is obtained for all the above methods and traced operating condition of temperature. The simulation is done using MATLAB software and compares the output of above four different methods. Model Reference Adaptive controller has given better result compare to all other methods. And also compare the various time domain specifications of different controller. Continuous reactors (alternatively referred to as flow reactors) carry equipment as a flowing stream. Reactants are continuously fed into the reactor and emerge as continuous stream of product. Continuous reactors are used for a wide variety of chemical and organic processes within the food, chemical and pharmaceutical industries. A survey of the continuous reactor market will throw up a daunting variety of shapes and types of machine. Beneath this variation however lie a relatively small number of key design features which determine the capabilities of the reactor. When classifying continuous reactors, it can be more helpful to look at these diagram features rather than the whole system. As with any type of procedure equipment, the purpose of classification is to ensure that the best tool is used for the job. It is therefore important to recognize that continuous reactors are part of a larger equipment group which also includes a group reactor. The merits of a group reactor should therefore not be ignored when looking for the optimum solution to a process problem. For this reason, the subject is introduced with a brief analyzed of the merits of both batch and continuous reactors. Checking condition inside the case of a continuous stirred tank reactor (CSTR).The prospered (or agitator) blades on the shaft for mixing and the baffle at the bottom of the image which also helps in mixing. In a CSTR, one or more fluid reagents are introduced into a tank reactor assembled with a fomenter while the reactor effluent is removed. The impeller stirs the reagents to ensure proper mixing. Simply dividing the volume of the tank by the average volumetric movement rate through the tank gives the residence time, or the average amount of time a discrete quantity of reagent spends inside the tank. Using chemical kinetics, the reaction's expected percent completion can be calculated. In a CSTR, one or more fluid reagents are introduced into a tank reactor equipped with an foment. The impeller whips the reagents to ensure desired mixing. Some points of CSTR:

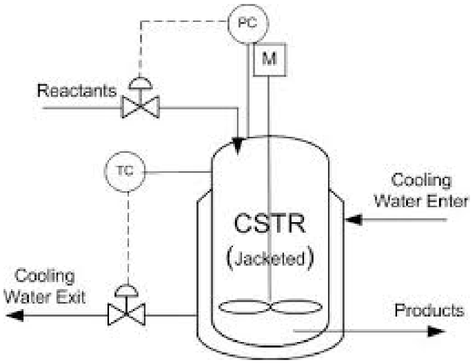

Figure 1. CSTR

1. At steady-state, the flow rate in must equal the quantity flow rate out, otherwise the vessel will overflow or go empty (transient state).
2. The reaction process at the reaction rate associated with the final (output) concentration. Often, it is economically beneficial to operate several CSTR in 16series. This allows, for example, the first CSTR to operate at a higher reagent Concentration and therefore a higher reaction rate. In these cases, the sizes of the reactors may be varied in order to minimize the total capital investment required to implement the process. It can be seen that an infinite number of infinitely small CSTRs operating in series would be equivalent to a PFR .The behavior of a CSTR is often approximated or modeled by that of a Continuous Ideally Stirred-Tank Reactor (CISTR). All calculations performed with CISTRs assume perfect mixing. If the residence time is 5-10 times the mixing time, this approximation is valid for engineering purposes. The CISTR model is often used to simplify engineering calculations and can be used to describe research reactors. In practice it can only be approached, particularly in industrial size reactors.

1. Mathematical Modeling of CSTR

This Mathematical Modeling helps to find the exact outputs for system, this done by predetermined formulas and constants.

$$\begin{pmatrix}\text{Rate of}\\ \text{accumulation}\\ \text{within the system}\end{pmatrix} = \begin{pmatrix}\text{Rate of heat in}\\ \text{to}\\ \text{the system}\end{pmatrix} + \begin{pmatrix}\text{Rate of flow}\\ \text{out of the system}\end{pmatrix} + \begin{pmatrix}\text{Rate of heat}\\ \text{generated by the chemical}\\ \text{reaction within the system}\end{pmatrix} \text{.....(1.1)}$$

Mass and energy balance equation of CSTR

$$\frac{dC_A(t)}{dt} = \frac{q(t)}{v}\left(C_{A0(t)}\right) - K_0 e^{\left(\frac{-E}{RT(t)}\right)} CA(t) \quad \ldots (1.2)$$

$$\frac{dT(t)}{dt} = \frac{q(t)}{v}\left(T_0(t) - T(t)\right) -$$
$$\left((-\Delta H)K_0\right)C_A(t)e^{\left(\frac{-E}{RT(t)}\right)}$$
$$+\frac{\rho_c C_{pc}}{\rho C_p V} q_c(t)\left\{1 - e^{\frac{-hA}{q_c(t)\rho t_p}}\right\}\left(T_{c0}(t) - T(t)\right) \quad \ldots (1.3)$$

Where,

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

T(t)- Reactor Temperature in Kelvin

At steady state,

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

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

$$f_1(C_A, T) = 0 = \frac{q(t)}{v}(C_{Ao}(t) - C_A(t))$$
$$-k_o e^{\left(\frac{-E}{RT(t)}\right)} C_A(t) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1.4)$$

$$f_2(C_A, T) = 0 = \frac{q(t)}{v}(T_o(t) - T(t))$$
$$-((-\Delta H)K_o C_A(t)e^{\left(\frac{-E}{RT(t)}\right)}$$
$$+\frac{\rho_c C_{pc}}{\rho C_p V} q_c(t)\left\{1 - e^{\frac{-hA}{q_c(t)\rho t_p}}\right\}(T_{co}(t) - T(t)) \ldots (1.5)$$

II. MODELING OF STATE SPACE EQUATION OF THE SYSTEM

The general state space model is following that,

$$\dot{x} - Ax + Bu \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.1)$$

$$y = Cx + D \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.2)$$

Where,

u= q_c (t) coolant flow rate L/min

$$\begin{bmatrix} X_1 \\ X_2 \end{bmatrix} = \begin{bmatrix} C_A \\ T \end{bmatrix}$$

$$\dot{x} = \begin{bmatrix} \frac{\partial f_1}{\partial x_1} & \frac{\partial f_1}{\partial x_2} \\ \frac{\partial f_2}{\partial x_1} & \frac{\partial f_2}{\partial x_2} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} \partial f_1 / \partial u \\ \partial f2 / \partial u \end{bmatrix} \text{……………… (2.3)}$$

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

$$A=\begin{bmatrix} -12.1455 & -0.04692 \\ -2229.1 & -9.3856 \end{bmatrix}$$

$$B=\begin{bmatrix} 0 & 1.5033 \end{bmatrix}$$

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

D=0

Calculation for finding Transfer function

For q_c =97 L/min

C_A =0.08235 mol/Lit

T =443.4566k

By using values we get,

K_1 =11.586

K_2 =0.5891

The system transfer function,

$$G(s)=\frac{1.788s+15}{s^2+18.11s+10.62}$$

Table 1. Normal Operating condition for CSTR

SL.NO	Process Variable	Normal Operating Condition
1	Concentration(CA)	0.0885 mol/lit
2	Reactor Temperature(T)	441.1475K
3	Volumetric flow rate(q)	100 L/min
4	Reactor volume(v)	100
5	Feed Concentration(CAf)	1 mol/Lit
6	Feed Temperature(Tf)	350 K
7	Coolant Flow rate(qc)	97 L/min
8	Heat of Reaction(ΔH)	2e5 cal/mol
9	Reaction rate constant(Ko)	7.2e10/min
10	Coolant temperature(Tcf)	350 K
11	Activation Energy term(E/R)	9980 K
12	Heat Transfer term(hA)	7e5 cal(min*K)

Table 2. Transfer function for different operating points

S.NO	Q_C(lit/min)	C_a (mol/lit)	temperature	Transfer Function
1	103	0.0989	439.7763	$system\,1=\frac{1.582s+16.71}{S^2+20.34s+10.22}$
2	106	0.1110	436.3091	$system\;2=\frac{1.681s+15.87}{S^2+19.2s+10.36}$
3	109	0.1254	433.6921	$system\,3=\frac{1.788s+15}{S^2+18.11s+10.62}$

III. PROPOSED SYSTEM

1. PID controller

A proportional integral derivative controller (PID controller) is a control loop feedback mechanism (controller) commonly used in industrial control systems. A PID controller continuously calculates an error value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error over time by adjustment of a control variable, such as the position of a control valve, a damper, or the power supplied to a heating element, to a new value determined by a weighted sum:

$$U(t)=K_p e(t)+K_i\int e(\tau)d\tau+K_d\frac{de}{dt} \quad \text{…… (3.1)}$$

By taking Laplace of the above equation

$$G_{PID}(S)=\frac{U(S)}{E(S)}=K_p\left(1+\frac{1}{T_i(s)}+T_d(s)\right) \quad \text{…..(3.2)}$$

$$U(s)=K_p E(s)+K_i\frac{1}{s}E(s)+K_d sE(s) \quad \text{…… (3.3)}$$

A proportional controller (Kp) will reduce the rise time, but never eliminate the steady-state error. An integral control (Ki) will have the effect of eliminating the steady-state error, but it may make the transient response worse the response becomes more oscillatory and needs longer to settle, the error disappears. A derivative control (Kd) will have the effect of increasing the stability of the system, reducing the overshoot, and improving the transient response. Adjustment based on rate of change of errors. Also, differentiation of a signal amplifies noise and thus this term in the controller is highly sensitive to noise in the error term, and can cause a process to become unstable if the noise and the derivative gain are sufficiently large.

Table 3. Trial and Error method Tuning

S.No	Gains	Temperature process
1	Kp	2-10
2	Ki	2-10
3	Kd	0-5

2. FUZZY LOGIC

Fuzzy logic is widely used in machine control. Fuzzy logic is a form of logic that is the extension of Boolean logic, which incorporates partial values of truth. Instead of sentences being "completely true" or "completely false," they are assigned a value that represents their degree of truth. In fuzzy systems, values are indicated by a number (called a truth value) in the range from 0 to 1, where 0.0 represents absolute false and 1.0 represents absolute truth. Fuzzification is the generalization of any theory from discrete to continuous. Fuzzy logic is important to artificial intelligence because they allow computers to answer „to a certain degree‟ as opposed to in one extreme or the other. In this sense, computers are allowed to think more 'human-like' since almost nothing in our perception is extreme, but is true only to a certain degree. Through fuzzy logic, machines can think in degrees, solve problems when there is no simple mathematical model. It solves problems for highly nonlinear processes and uses expert knowledge to make decisions. Fuzzy logic has the advantage that the solution to the problem can be cast in terms that human operators can understand, so that their experience can be used in the design of the controller. This makes it easier to mechanize tasks that are already successfully performed by humans.

3. MODEL REFERENCE ADAPTIVE CONTROL

Model Reference Adaptive System is one of the important adaptive controllers. This strategy is used to design the adaptive controller that works on the theory of adjusting the controller parameters so that the output of the actual plant tracks the output of a reference model having the same reference input.

The standard implementation of MRAC abased system is shown in figure2.The system has an ordinary feedback loop composed of the process and controlled parameters. The parameters are changed on the basic of feedback from error, which is the difference between the output of system and output of reference model

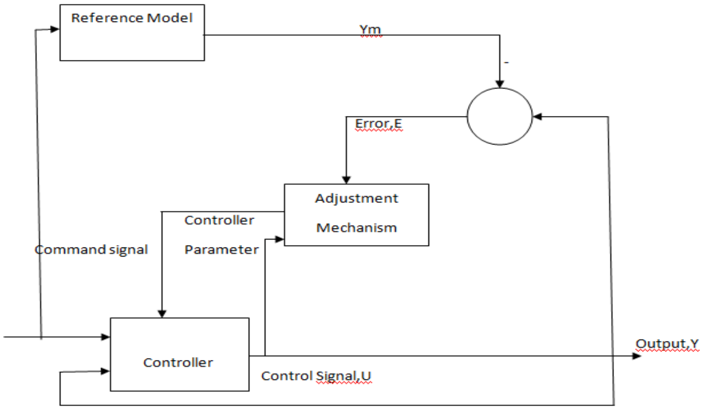

Figure 2. Model Reference Adaptive Controller

The ordinary feedback loop is called the inner loop and the parameter adjustment loop is called outer loop. The mechanism for adjusting the parameter in a model reference adaptive system can be obtained by using a gradient method or by applying Lyapunov's stability theory.

IV. SIMULATION RESULTS

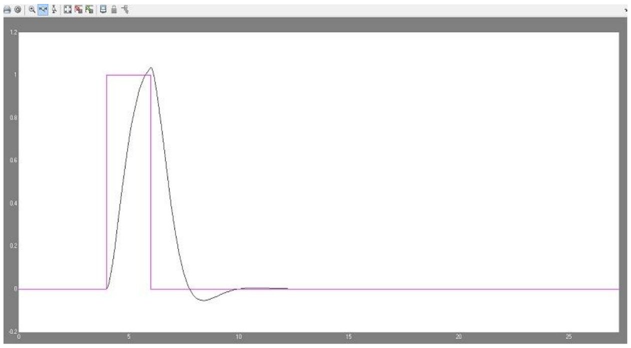

Figure 3. Servo Response of Trial and Error Method

The above figure 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

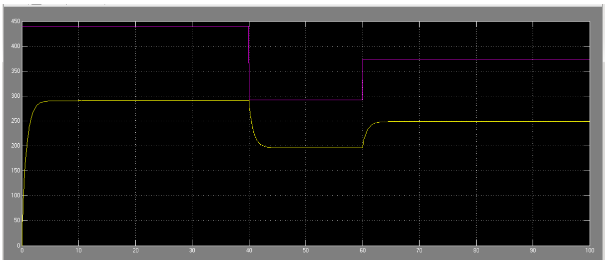

Figure 4. Servo response comparison of Ziegler-Nichols PID-controller and fuzzy PID-Controller

The above figure shows the servo response of Ziegler-Nichols PID Controller and Fuzzy PID Controller. In the Fuzzy PID controller, The process output meet thedesired set point quickly with less oscillation than the Ziegler NicholsPIDcontroller.The controller parameters are:

Kp=0.7878;Ki=3.0857;Kd=0.7714

Fig 5 shows schematic block diagram of Model Reference Adaptive Controller

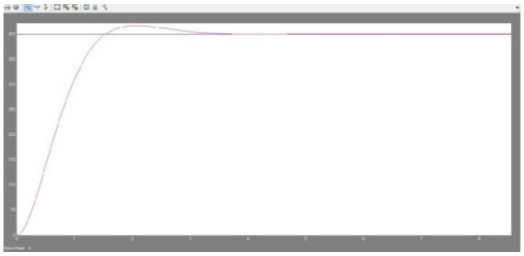

Figure 5. MordenAdapative reference control

The above figure shows the output response of MARC. It meets the desired set point quickly without overshoot. The output responses clearly show Model Reference Adaptive controller is the best controller it reach the set point quickly without overshoot then all other controllers.

V. CONCLUSION

In this paper, comparative studies of different controllers are studied and performance is evaluated according to time domain functions. It is observed that all controllers able to maintain the set point at the desired value but ZN-PID ,Fuzzy based controllers has slight overshoot, Model Reference Adaptive controller has no overshoot and settles quickly. So it conclude that Model Reference Adaptive Controller is the best controller then other controllers

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