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Controller Design for Continuous Stirred Tank Reactor Using Adaptive Control

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Abstract: Continuous Stirred Tank Reactor (CSTR) is an important issue in chemical process and a wide range of research in the area of chemical engineering. Temperature control of CSTR has been an issue in the chemical control engineering since it has highly non-linear complex equations. This study presents problem of temperature control of CSTR with the adaptive controller. The simulation is done in MATLAB and result shows that adaptive controller is an efficient controller for temperature control of CSTR than PID controller.

Key words: Continuous stirred tank reactor, temperature, control, MATLAB, PID controller

INTRODUCTION

In chemical engineering segment the reactors are the indispensible and leading influential factor for any industry. The study of dynamic characteristics in the domain of continuous stirred tank reactor elevates the computational efficiency of system. The keen observation of parameters in subject ensures reliability in configuring the control system design. The CSTR lies in open source system category which states that the input/output flow of material is not restricted. This steady-state system operates on the conditions that are independent of time. Input flow and extraction of materials in reactor is a continuous process. The CSTRs function in constant frame for the products to get mixed thoroughly and the contents possess relatively uniform properties like temperature, density, etc. throughout. Also, the conditions of input and output stream in tank are directed to constant. The controlling of continuous stirred tank reactor has always been an issue of controversies and interest parallely among the students reason being the non-linear dynamics (Juang *et al*., 2008). Most of the conventional controllers are dedicated for the systems with linear time invariant applications. However, in real environment, the physical properties of system (wear and tear) are responsible for changes in functional parameters and non-linear characteristics which cannot be neglected. Furthermore, focus is demanded to deal with system that have uncertainties in real applications (Soheilirad *et al*., 2012).

Hence, the role of intelligent and adaptive controllers with working parameters same as above points are of great importance (Rahmat *et al*., 2011). This study discuss about some conventional and efficient methods of CSTR control and stability.

MATHEMATICAL MODEL

Chemical reactions are classified into exothermic or endothermic processes that seek the input or output of energy to maintain the constant temperature of system. Figure 1 represents the CSTR process model with schematics of operation. The proposed CSTR acquires irreversible exothermic reaction mode as the working atmosphere. The heat of the reactor is isolated by coolant medium that backdrop the reactor in form of jackets. The fluid stream of A is fed to the reactor in presence of catalyst arranged at core of rector. The stirrers blend the components of input flawlessly which after forth is extracted out of exit valve. The jacket which surrounds the reactor also has feed and exit streams.

The jacket is alleged to be mixed meticulously at temperature poorer than reactor (Banu and Uma, 2007a, b). The system can be analyzed mathematically by examining the components mass at input and output and energy balance principle in reactor.

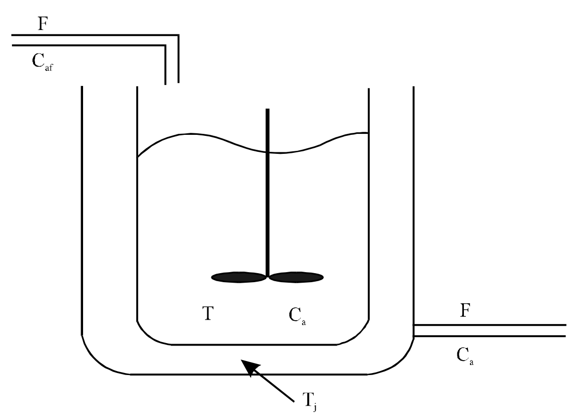

Fig. 1: CSTR process flow

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Accumulation of componentmass = Componentmass in-Componentmassout+Generation of component mass (1)

(Accumulation U+PE+KE) = (H+PE+KE)in-(H+PE+KE)out+Q-Ws (2)

The dynamic equation of CSTR is (Hong and Cheng, 2012; Adetola *et al*., 2009):

$$\frac{dC_a}{dt} = \left(\frac{F}{V}\right)(ca_f\text{-}C_a)\text{-}k_0\exp\left[\frac{E}{R.(T+460)}\right]C_a \quad (3)$$

$$\frac{dT}{dt} = \left(\frac{F}{V}\right)(T_f\text{-}T_a)\text{-}\frac{\Delta H}{\rho C_p}\left[k_0\exp\left[\frac{-E}{R.(T+460)}\right]C_a\right]\text{-}\left(\frac{UA}{\rho C_p V}\right)(T\text{-}T_j) \quad (4)$$

Where:

T_j = Temperature of input jacket
C_a = The concentration of input and output
T = Temperature of input and output

The intention of control is to influence the jacket T_j and keep the system temperature saturated.

CONTROLLING METHODS OF CSTR

PID control: As stated by Aslam and Kaur (2011), an offset can be led by proportional controller between the actual output and the preferred set points. The cause following this is process input, controller output and process output that attains fresh equilibrium values prior to error going down to zero. For the controller output to be proportional with integral of error, desired compensation is introduced (Kozakova, 2008; Bucz *et al*., 2008). This is in other words acknowledged as proportional integral control. The controller output adjusts itself till the error signal is received in controller. Hence, the error signal is drowned to zero by integral of error. Another term integral derivative control is introduced in the system to account derivate of error or current rate of change. The knowledge of error solves certain complex computational analysis like behavior and direction of error. The implementation of PID control in process overshoots and control delay time for problems in inverse response of over going process. The problems are tackled efficiently but inject instability in terms of setting and rise time.

Fuzzy controller: Fuzzy logic was highly entertained in diverse applications of engineering segment just after introduction of mathematical aids by McCulloch and Pitts in 1943 and Zadeh in 1965, respectively. Famous as the braches of Artificial Intelligence both emulates the human propensity of learning from past experiences and adapting itself comprehensive and accordingly. The fuzzy control scheme cooperates in eradicating of delay times and inverting response populated by PID controller. Rise time and settling time thus gains improved value by it (Sastry *et al*., 2012). The scheme of fuzzy control (Ali and Abu Khalaf, 2004) is based on simple design with tuning procedures by employing unified domain for fuzzy sets. The tuning in addition can be achieved via adjustments of parameter's couple based on perceptible general guidelines (Ahadpour, 2011). Furthermore, the synthesis of FLC has more elastic approach and consequently any additional identified progression acquaintance or nonlinearity can be included easily in controller law. However, the fuzzy logic based PI controller is in-efficient during real time due to integration operation for non-linear system while fuzzy PD controller encounters with considerable difficulty in mitigating the steady state error (Pratumsuwan *et al*., 2010; Brehm and Rattan, 1993).

Neural network controller: The artificial neural network is parallel interconnected enormous network with uncomplicated elements whose hierarchical are reminiscent of biological neural systems (Hussain *et al*., 2007). By comparing the input and output threads a neural network can represent non-linear systems.

Artificial neural networks are the systematic alternatives adjacent to conventional approaches to trounce assumptions of linearity, variable independence and normality (Malar and Thyagarajan, 2009). The study of modeling the isothermal CSTR by virtue of neural networks is contrived in this study of which the training is configured using data sets obtained by component balance equations (Sharma *et al*., 2004). The simulations demonstrate about the advanced controllers based neural network implementation for set-point tracking case to force variables of process output. The target values are forced efficiently within realistic rise and settling times.

Adaptive control: Studying the simulation results by Vojtesek and Dostal (2010) reflects the behavior of non-linear lumped-parameters system for adaptive control symbolized by CSTR reactor. The choice of external linear model classifies the used adaptive control in range of delta models parameters (Tuan and Minh, 2012; Qiao and Wang, 2011). The parameters are anticipated recursively during the process of control. Three diverse recursive methods of least mean squares were employed to approximate values of parameters and configure two control systems and Degrees of Freedom (2DOF). The results of research exhibit elevated values of control response. However, at the commencement of control when the information about the system is minimal, the results confirm discreet nature of output. Course of output temperature have swift response because of decline in worth of weighting factor. For stumpy value of weighting factor there should be some diminutive overshoots. Comparison of 1 DOF and 2 DOF configurations present slower course of output variable for 2 DOF but modification of activation value are smoother. The final investigation evaluates the responses for assorted identifications that signify over viewing of forgetting factors because no significant dissimilarity is observed in results.

Hybrid controller: The study by Vishnoi *et al*. (2012) is the comparative analysis concerning the performance of hybrid fuzzy controller and PID controller for concentration control of isothermal type continuous stirred tank reactor. The study simulates engineers to carry forward the chemical processes in any industry. Isothermal continuous stirred tank reactor is classified in the reactors category that operates on unvarying temperature. A mathematical model of isothermal CSTR and implemented PID controller alongside with PD fuzzy controller is developed in study for controlling product concentration in reactor irrespective to the conflicts and delays (Fadaei *et al*., 2013). Analyzing the time domain of controller for studying the performance in diverse controllers illustrates that PD fuzzy controller performance is superior compared to the product concentration of isothermal CSTR. The time response analysis reveals the fact that agreeable control performance is observed in hybrid fuzzy controller.

PSO based PID controller: In study by Agalya and Nagaraj (2013), non-linear feedback controller design is experimented for concentration control of Continuous Stirred Tank Reactors (CSTR) with strong non-linearities. Continuous Stirred Tank Reactor (CSTR) is a conventional and simple approach in chemical process while multiple industrial applications seek resolutions for specific chemical potency of chemicals under investigation. The PID controllers pedestal on Particle Swarm Optimization (PSO) algorithm is attempted to control the concentration of Continuous Stirred Tank Reactor (CSTR) (Yu *et al*., 2008; Bingul and Karahan, 2011; Sharma *et al*., 2009; Lee and Ko, 2009). The controller can be anticipated by criterion and Performance indexes. The Integral Square Error (ISE) is employed to guide PSO algorithm for searching controller parameters such as K_p, K_i and K_d. The simulation results of comprehensive simulations with PID and I-PD controller structures states about the superiority followed by PSO based PID controller tuning approach for better performance in terms of evaluation parameters compared with other conventional methods tuning PID.

MODEL REFERENCE ADAPTIVE CONTROLLER

The reference model demonstrates about the controlling method outputs response towards command signal (set point). A comparison among the actual output process and model output is made to provide the possible route that identifies the specifications for a servo problem. The difference among the outputs is implemented to adjust the controller gain in a way minimizing the integral square error:

$$\text{Minimized ISE} = \int_0^t \left[\theta_m(t)\right]^2 dt \quad (5)$$

The MRAC is the union of two loops. The loop placed at inner side is ordinary feedback loop. The outer loop is sourced by adaptation mechanism that resembles feedback loop. The model output and the process output are the set points and actual measurements, respectively. The key concentration is required in illuminating the structure of adaptation mechanism in a way that leads stable system (Brehm and Rattan, 1993) (Fig. 2).

The Lyanunov Method and Gradient Method are two approaches for parameters adjustment. The law of adaptation employs the error among model and process output. The parameters are adjusted to meet with requirements of minimizing the error among Process and Reference Model.

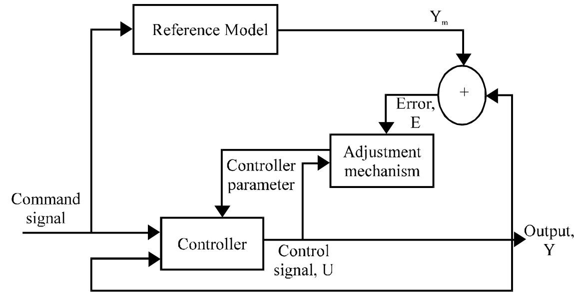

Fig. 2: Model reference adaptive controller

ADAPTATION LAW

The adaptation law states a set of parameters that minimize the error model and plant outputs. Hence, adjustments are made in the parameters of controller to diminish error towards zero point. A number of adaptation laws are researched recently out of which the Gradient and Lyapunov approaches are main methods. The Gradient approach of MIT rule was assembled for development of adaptation law (Hussain *et al*., 2007).

MIT rule: The MIT rule is authentic approach for modeling of reference adaptive control. The name was acquired by inspiration of instrumentation laboratory (now the Draper laboratory) at Massachusetts Institute of Technology (MIT), USA.

The MIT rule can be demonstrated by consideration of closed loop system that cooperates with adjustable parameters of controller. The model output Y_m specifies the closed loop response. Error (e) is the difference in the output system (Y) and output of Reference Model (Y_m). The equation describing error is states as:

$$e = Y - Y_m$$

One possibility is to adjust parameters in such a way that the loss function J(θ) is minimized:

$$J(\theta) = \frac{1}{2}e^2$$

To make J small, it is reasonable to change the parameters in the direction of negative gradient of J. That is:

$$\frac{d\theta}{dt} = -\gamma\frac{\delta J}{\delta\theta} = -\gamma e\frac{\delta e}{\delta\theta}$$

This is the celebrated MIT rule. The partial derivative $\delta e/\delta\theta$ is called the sensitivity derivative of the system, tells how the error is influenced by the adjustable parameter, γ is called adaptation gain.

SIMULATION WITH PID CONTROLLER

CSTR: The CSTR is modelled with MATLAB/SIMULINK with following parameters in Table 1.

Equation 3 and 4 are realized with above parameters in MATLAB to create s-function for SIMULINK Model as shown in Fig. 3.

Table 1: Parameters of CSTR

Variables	Values
Ea	32400 (BTU/lbmol)
K0	15×10^{12} (H^{-1})
dH	-45000 (BTU/lbmol)
U	75 (BTU/h-ft^2-of)
Rho×C_p	53.25 (BTU/ft^3
R	1.987 (BTU/lbmol-of)
V	750 (ft^3)
F	3000 (ft^3/H)
Ca_f	0.132 (lbmol/ft^3)
T_f	60 (of)
A	1221 (ft^2)

Table 2: Parameters of PID

Parameters	Notation	Values
Proportional gain	K_p	5.0
Integral gain	K_i	50.0
Derivative gain	K_d	0.5

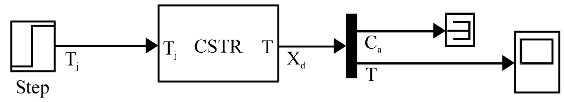

Fig. 3: Simulink Model for CSTR with set point

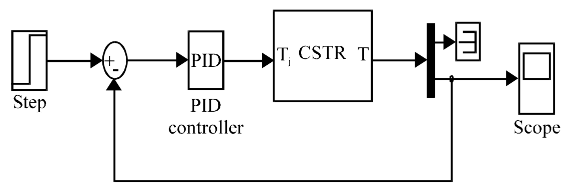

Fig. 4: Simulink Model for CSTR with PID

CSTR with PID controller: The PID Controller algorithm sites three separate constant parameters which accordingly sometimes are referred as the integral, derivative and proportional values denoted by P, I and D, respectively. Employment of these values can be interpreted in terms of time where P is the present error, I is accumulation of past error experiences and D stands for prediction of future errors based on current change rate.

The PID controller is used with following parameters in Table 2. Figure 4 shows the CSTR Model connected with PID.

CSTR with adaptive controller
Parameters:
Adaptive Gain (γ) = γ = 1e-15;
PID parameters
Kp = 10
Ki = 30
Kd = 0.05

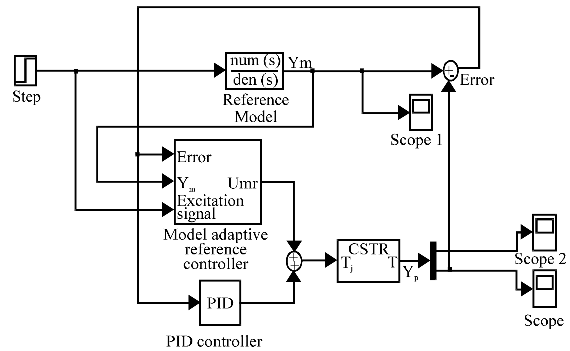

Fig. 5: Simulink Model of CSTR with PID and model reference adaptive controller

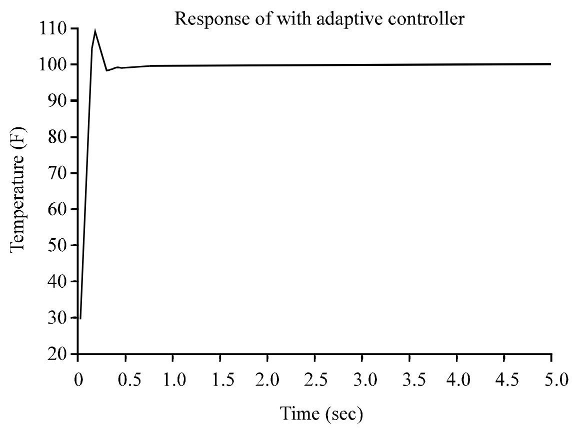

Fig. 6: Temperature response of CSTR along with adaptive controller

Table 3: Comparison of time domain parameters

Time domain parameters	Without controller	PID controller	Adaptive controller
Rise time	0.5353	0.1774	0.1424
Overshoot	46.5332	23.8254	9.9334
Peak time	0.9197	0.3532	0.1803
Settling time	1.2084	1.3135	0.3548

Simulink Model of CSTR with PID and model reference adaptive controller is shown in Fig. 5. Figure 6 shows the response of CSTR temperature when set point is 100 F.

Figure 7 showing the temperature response of CSTR when set point is 100 F. Figure 7 clearly showing that adaptive controller gives better response than PID. Figure 8 shows the response of CSTR temperature when set point is 0.0714 lbmol/F^2.

Adaptive controller: Figure 9 showing the concentration response of CSTR when set point is 0.0714 lbmol/F^2. Figure 9 clearly showing that adaptive controller gives better response than PID. Table 3 shows the comparison of time domain parameters.

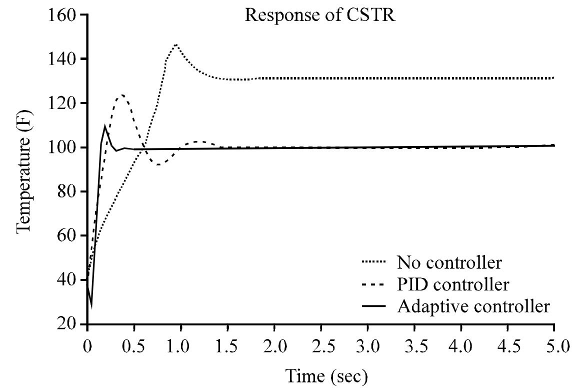

Fig. 7: Temperature response of CSTR with various controller

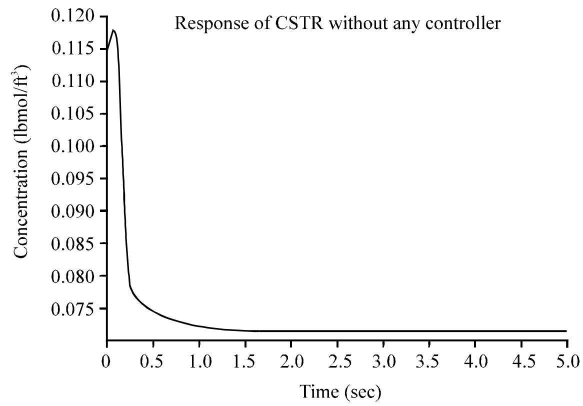

Fig. 8: Concentration control of CSTR with adaptive controller

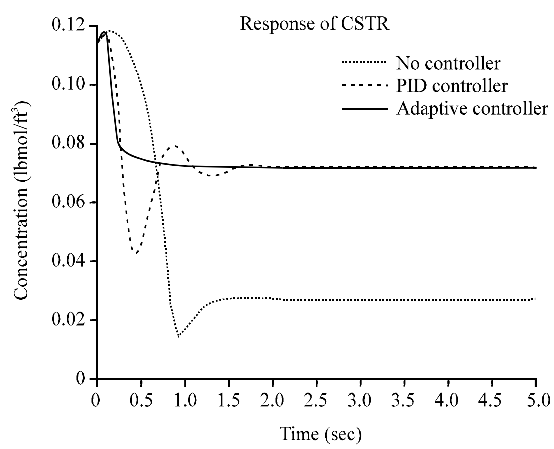

Fig. 9: Concentration control of CSTR with various controllers

REAL TIME IMPLEMENTATION

Figure 10 and 11 show the real-time implementation temperature and concentration control of CSTR.

Fig. 10: Real time model of CSTR process

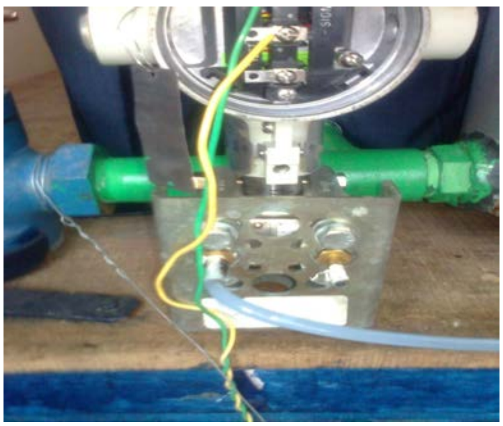

Fig. 11: Controller design for CSTR process

CONCLUSION

The temperature control of CSTR with MIT adaptive controller is presented in this study. CSTR is modelled in MATLAB with its complex non-linear equations and simulation has been shown without any controller wirth PID controller and adaptive controller. The results clearly show that adaptive controller efficiently provide temperature control for CSTR with optimum overshoot and rise time. Further research can be proposed as the optimization of parameters of adaptive controller with some optimization algorithm to get faster responses.

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