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Research Article

Adaptive Controller Design for Continuous Stirred Tank Reactor

[1]K. Prabhu and [2]V. Murali Bhaskaran
[1]Department of Electronics and Instrumentation Engineering, Kongu Engineering College,
Erode, Tamilnadu-638 052, India
[2]Department of Computer Science Engineering, Dhirajlal College of Technology, Salem,
Tamilnadu-636 309, India

Abstract: Continues 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.

Keywords: CSTR, ISE, MATLAB, MIT rule, MRAC, PID controller, temperature control

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 (Mani *et al*., 2009). 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. Further sections are about the configuration, simulation and analysis of hybrid approach to control the CSTR system.

MATERIALS AND METHODS

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 (1) and energy balance principle (2) in reactor:

$$Accumulation\ of\ component\ mass = component\ mass\ in - component\ mass\ out + generation\ of\ component\ Mass \quad (1)$$

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

Corresponding Author: K. Prabhu, Department of Electronics and Instrumentation Engineering, Kongu Engineering College, Erode, Tamilnadu-638 052, India

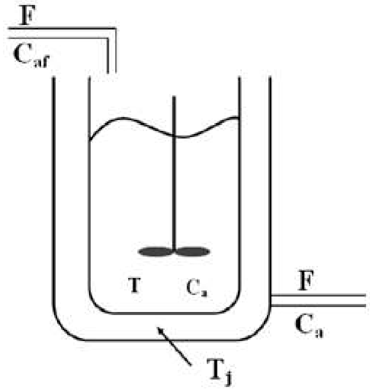

Fig. 1: CSTR process flow

The dynamic equation of CSTR is (Banu and Uma, 2007a, b):

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

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

where, T_j is temperature of input jacket and c_a, T are, respectively the concentration and temperature of input and output. The intention of control is to influence the jacket T_j and keep the system temperature saturated.

PID control: As stated in Farhad and Gagandeep (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 (1943) and Zadeh (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 and Ravi Kumar, 2012). The scheme of fuzzy control (Emad 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 and Thongchai, 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 (Mani *et al*., 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 of Vojtesek and Dostal (2010) reflects the behavior of nonlinear 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; Ji-Hong and Hong-Yan, 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 the work 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 in paper (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 paper for controlling product concentration in reactor irrespective to the conflicts and delays (Farzad *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 of Agalya and Nagaraj (2013) non-linear feedback controller design is experimented for concentration control of Continuous Stirred Tank Reactors (CSTR) with strong nonlinearities. 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, 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:

$$Minimized\ ISE = \int_0^t [\theta_m(t)]^2 dt \quad (5)$$

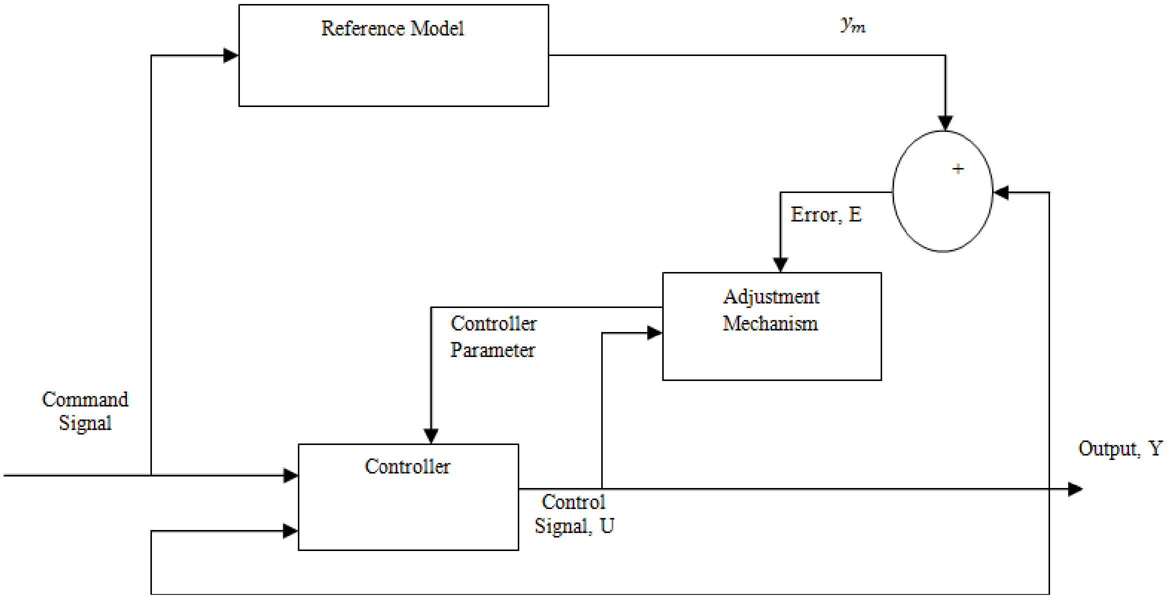

Fig. 2: Model reference adaptive controller

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.

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), U.S.A.

The MIT rule can be demonstrated by consideration of closed loop system that cooperates with adjustable parameters of controller. The model output YM specifies the closed loop response. Error (e) is the difference in the output system (Y) and output of reference model (YM).

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 $\frac{\delta e}{\delta\theta}$ is called the sensitivity derivative of the system, tells how the error is influenced by the adjustable parameter, γ is called adaptation gain.

RESULTS AND DISCUSSION

CSTR: The CSTR is modelled with MATLAB/SIMULINK with following Parameters (Table 1).

Equations (3) and (4) are realized with above parameters in MATLAB to create s-function for SIMULINK model as shown in Fig. 3.

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 parameters obtained from the Ziegler-Nichols method as shown in Table 2.

Figure 4 and 5 shows the SIMULINK model for CSTR connected with PID controller.

CSTR with adaptive controller: The PID Controller parameters obtained from the Ziegler-Nichols method of tuning and gamma value from the MIT RULE as shown in the Table 3 as shown in Table 2.

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 clearly showing that adaptive controller gives better response than PID.

Figure 8 above shows the response of CSTR temperature when set point is 0.0714 lbmol/F^2.

Table 1: Parameters of CSTR

Variables	Values	Units
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

Parameter	Notation	Value
Proportional gain	K$_p$	5
Integral gain	K$_i$	50
Derivative gain	K$_d$	0.5

Table 3: Parameters of adaptive controller

Parameter	Notation	Value
Proportional gain	K$_p$	10
Integral gain	K$_i$	30
Derivative gain	K$_d$	0.05
Gamma	Gamma	1e-15

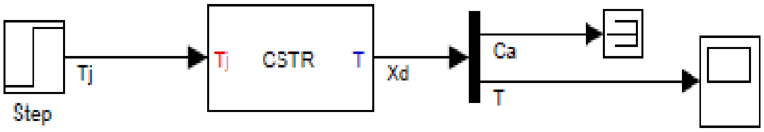

Fig. 3: SIMULINK model for CSTR with set point

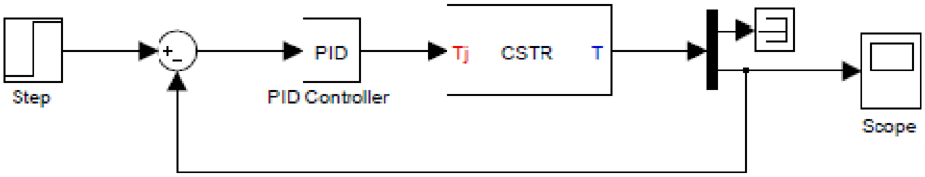

Fig. 4: SIMULINK model for CSTR with PID

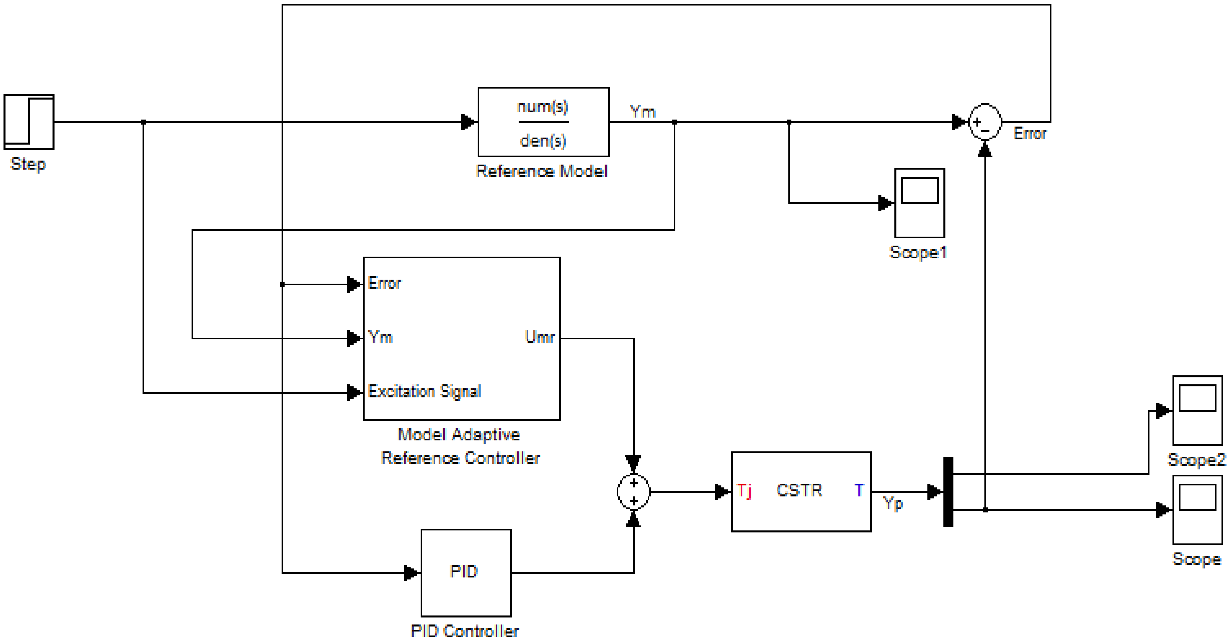

Fig. 5: SIMULINK model of CSTR with PID and model reference adaptive controller

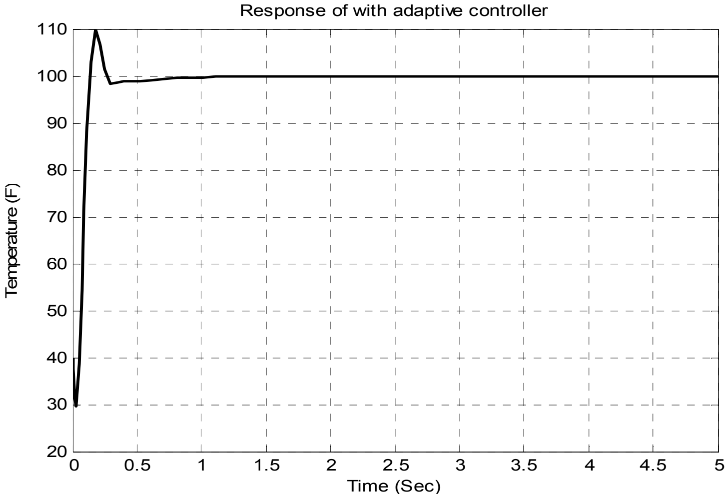

Fig. 6: Temperature response of CSTR along with adaptive controller

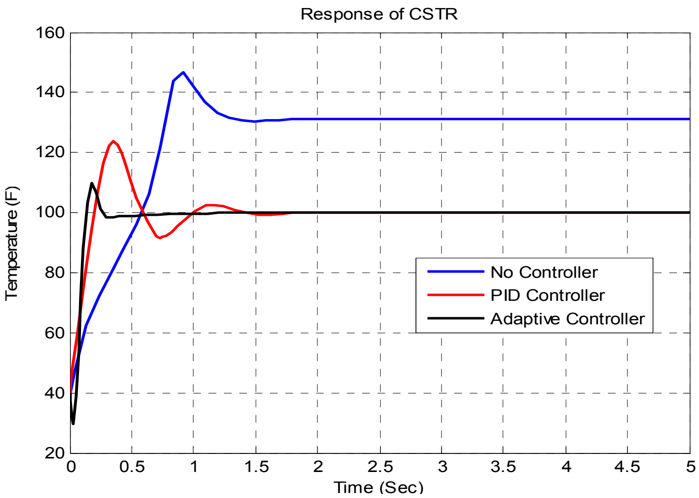

Fig. 7: Temperature response of CSTR with various controllers

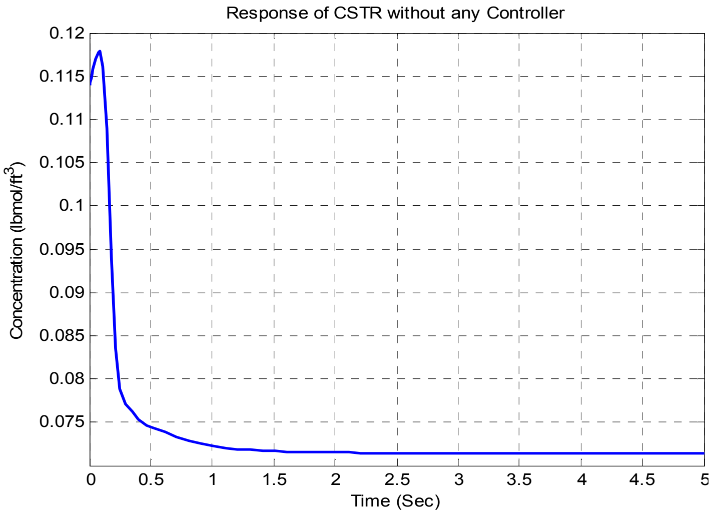

Fig. 8: Concentration control of CSTR with adaptive controller

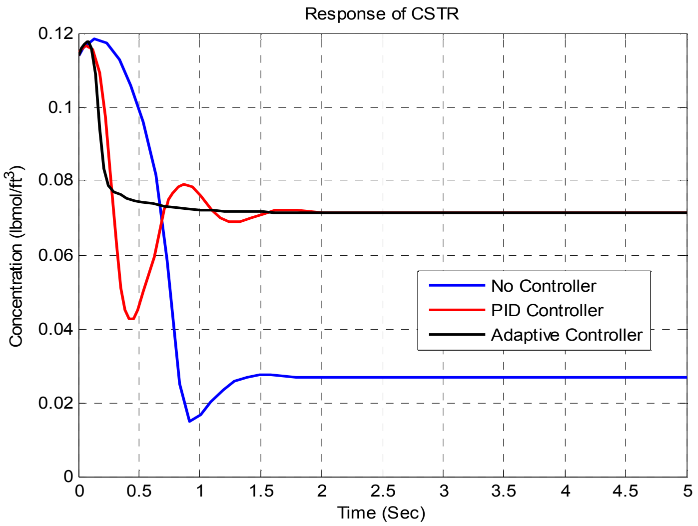

Fig. 9: Concentration control of CSTR with various controller

Table 4: Response of various controllers

	No controller	PID	Adaptive controller
Rise time (sec)	0.5353	0.1774	0.1424
Overshoot (%)	46.5332	23.8254	9.9334
Peak time (sec)	0.9197	0.3532	0.1803
Settling time (sec)	1.2084	1.3135	0.3548

Figure 9 below 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.

Hence the Table 4 clearly indicates that adaptive controller provides optimal controller parameters by reducing the Rise Time, Overshoot, Peak Time and Settling Time.

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, with PID Controller and adaptive controller. The Table 4 clearly shows that adaptive controller efficiently provide temperature control for CSTR with optimum overshoot and rise time. Further work can be proposed as the optimization of parameters of adaptive controller with some optimization algorithm to get faster responses.

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