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Fuzzy Logic Non-Isothermal Chemical Reactor

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Abstract**—** *Advance control system for non-isothermal chemical reactor is designed by using Simulink® in MATLAB. Non isothermal chemical reactor likes Continuous stirred tank reactor (CSTR) is a complex model and time consuming due to some expectations are needed. Thus, several advanced control strategies techniques have been introduced in modelling this complicated system. The advance control methods apply for PI and PID controller are adaptive control, cascade control, smith predictor, feed forward control and feedback control as well as auto tuning. The best advance control system will be selected and compared with fuzzy logic control system. It is deduced that fuzzy logic controller gives a better result than other controller.*

Keywords**—** *Auto tuning; CSTR; Fuzzy logic; PI controller; PID controller.*

I. Introduction

Chemical reactor has two main types, tubular reactor which has less mixing inside the reactant when the reactant flow inside it and stirred tank reactor which is a good mixer for reactant inside it [12]. Continuous stirred tank reactor (CSTR) is one of the reactors that commonly used in large scale production likes chemical and process industries [18]. This is because it exhibits highly nonlinear behaviour and usually has wide operating ranges [13]. It is very important to advance control system on CSTR because of its complex chemical process [7]. However, CSTR control system is frequently facing a regulator problem in which the temperature or concentration face a disturbance as when it is held at the desired values. Product concentration for a CSTR can be controlled by manipulating the feed flow rate, which changes the residence time for a constant chemical reactor [2]. Hence, simulation in MATLAB SIMULINK has been conducted to choose the best control system to handle the non-isothermal CSTR. In order to get an excellent controller, a very accurate and precise control system is needed. There are many control methods that has been studied such as adaptive control, neural network, cascade etc. [8]. However, the most common controller that has been used in the industries is PID controller because of its simplicity and tune less number of parameters [3]. The advance controls processes apply in this simulation are PI, PID, auto tuning and fuzzy logic. The methods apply for PI and PID are adaptive control, cascade control, smith predictor, feed forward control, and feedback control. These control systems are developed and then will be compared with each other to choose the best control system for non-isothermal CSTR.

II. CSTR Process Model

The non-isothermal CSTR is an essential industrial process that presents the opportunity for a various range of process dynamics. In control system view, the dynamics of non-isothermal CSTR are very nonlinear with unstable characteristics [19]. In addition, it may have parametric uncertainties, disturbances and un-modelled side reactions. These may cause the temperature of the reactor deviate from the reference value [18]. The deviation will reduce the quality of the product because the chemical reaction inside the CSTR is effected by the temperature.

Mass, component and energy balance equations is developed in order to describe the dynamic behavior of the system. The balance equations as following:

Basic mass balance of the system,

$$\frac{d(V)}{dt} = F_0 - F \tag{1}$$

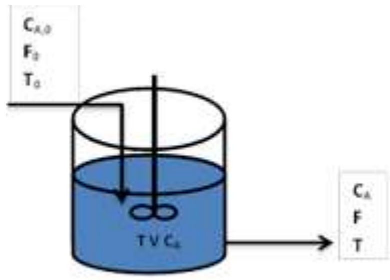

Fig.1. Non-Isothermal CSTR

The dynamic model for a non-isothermal CSTR is given as follows [16]:

$$\frac{dC_A}{dt} = \frac{F}{V}\left(C_{A,0} - C_A\right) - k_0 \exp\left(-\frac{E}{RT}\right) C_A \tag{2}$$

Where, k_0 is a first order reaction rate constant, $C_{A,0}$ is inlet concentration of A, F is steady state flow rate, ρ is density of A, C_p is specific heat capacity if A, $-\Delta H_r$ is heat of reaction, T is reactor temperature, T is reactor temperature, T_0 is inlet temperature and C_A is reactor concentration of A.

III. Control System

A. Feedback Control System

Feedback control system also commonly known as a closed loop control system develops an extra measure of the actual output because it will be compared with desired output response. In the feedback control system, the output signal is verified and then fed back to the input to produce a new output [5]. The feedback system plays significant roles in improving the performances of the control system [6]. It increases the accuracy of the system, reduces the effect of external disturbance and escalates the bandwidth of the system.

Closed loop transfer function:

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$$\frac{Output}{Input} = \frac{\theta_0}{\theta_i} = \frac{G}{1+GH} \quad (3)$$

Where G is gain of the controller or system, H is gain of the measurement system and Θ_e is error signal.

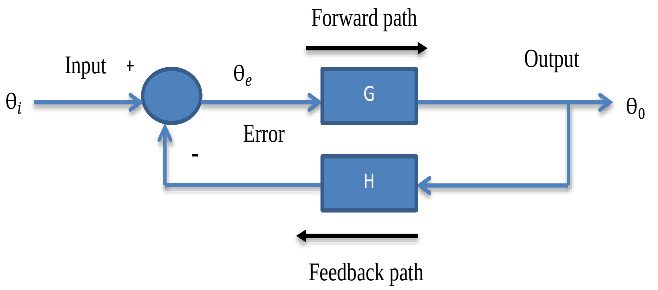

Fig. 2. Feedback control system block diagram

A. Feedforward Control System

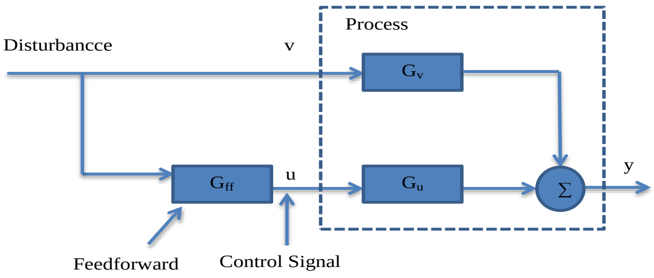

Fig. 3. Feedforward system block diagram

Feedforward control system or open loop control system is one of the control actions which independent from the output. The control system operation is very simple, as per the input signal directs the control element to respond, an output will be produced. According to technological studies, regardless of the final result, the system is feasible to follow its input command or set point[15]. This system is feasible to measure an impending disturbance before it hits the process [17].
The transfers function for the control system [9]:
Where U is control variable, v is disturbance and y is the output.

C. Cascade Control System

For cascade control system, single measured variable is controlled at two point control. By using the output of the primary controller it manipulates the set point of the secondary controller as if it were the final control element. The cascades control design take account of the possible disturbances in the process and regulates the control system to the disturbances that strongly degrades performance [4].

Refer to Figure 4 the inner loop is controlling the secondary process while the outer loop controls the primary process. Both of the loops are tuned in a systematic manner [10].

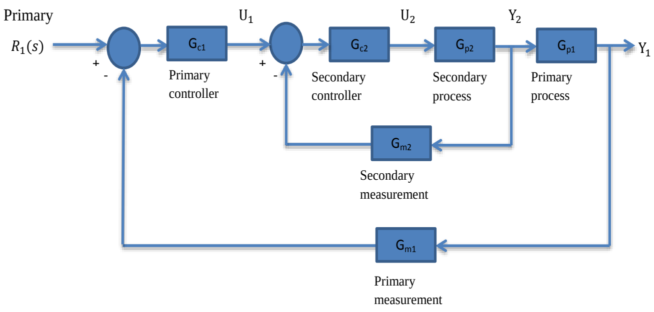

Fig. 4. Cascade control system

D. Smith Predictor Control

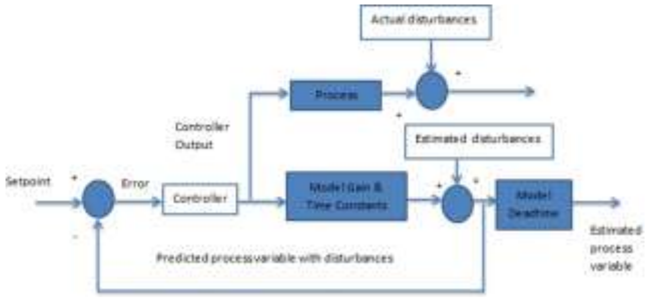

Fig. 5. Smith predictor control block diagram

Smith predictor control is a feedback control that has a minor loop. The minor loop uses to eliminate the actual delayed output and also to feed the predicted output to the primary controller at a given time instant in the future [1]. The Smith predictor control removes the time delay out of the control loop and lets feedback design based on a delay free system.

E. Adaptive Control System

Adaptive control is a set of technique to adjust the controllers in real time automatically. The objective of this control system is to achieve or maintain a desired level of performance of the control system when the parameters of the plant likes disturbance dynamic model are unknown or change in time [11]. The basic principle of adaptive control is producing a cancelling signal [14]. The signal interferes destructively with the primary signals in order to reduce them. The level of success in cancelling the primary signals is measured in order to adapt the cancelling signal. Hence, the reduction of undesired primary signal will increase.

$$U(s) = \frac{G_v(s)}{G_u(s)} V(s) \quad (4)$$

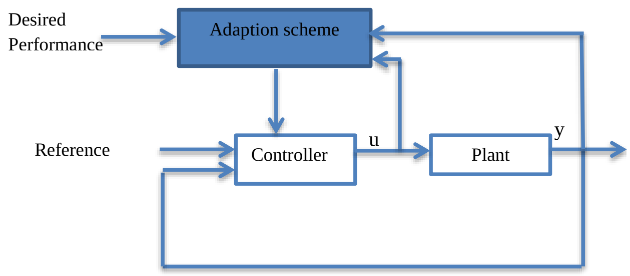

Fig. 6. Adaptive control system block diagram

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F. Fuzzy logic

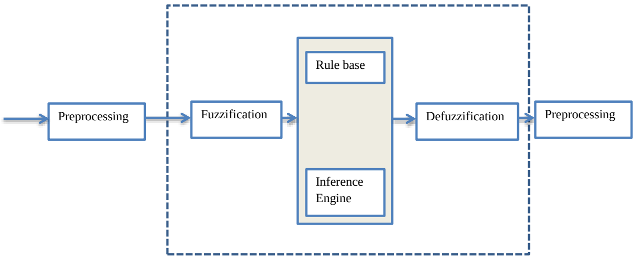

Fig. 7. Fuzzy logic control system block diagram

Fuzzy logic consist a set of fuzzy inference that works on imprecise reasoning that give a consequence action as the outcome. The implementation uses very flexible 'if then' logic instead of differential equations. Generally, in order to describe the system of interest, fuzzy logic uses simple rule rather than analytical equation, hence, making it easy to implement. Besides, this control system able to adjust automatically the priorities number of controlled variables.

IV. RESULTS & DISCUSSION

Figure 8 illustrates the step response of the open loop of the dynamic system. Based on the simulation, the dynamic system exhibits a process reaction curve which parameters of the controller is estimated. The output response of the open loop of the non-isothermal CSTR is obtained as shown in Figure 8 in order to determine the parameters. Manual tuning calculation is based on the parameters for Kp (process gain), T1 (time constant) and d1 (time delay).

Manual calculation for the control system has done to get the value of:

Time delay, d1 = 2 min

$$\text{Gain}, K_p = \frac{\Delta P}{\Delta MV} = \frac{2.8}{1} = 1 \qquad (5)$$

Time constant, T1=12 min-2 min =10min

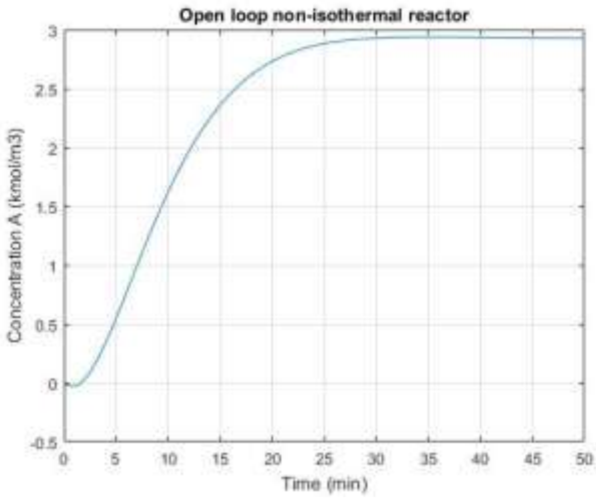

Fig. 8. Open loop for CSTR

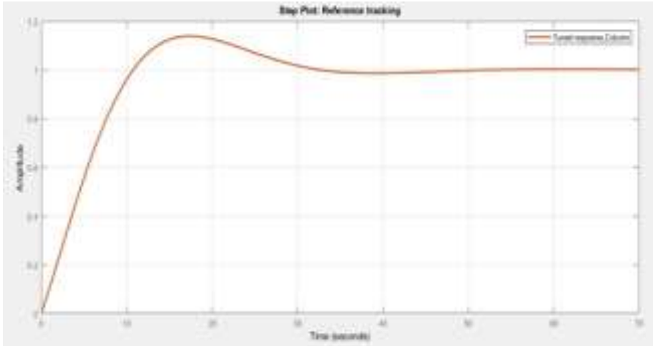

Fig. 9. PI step amplitude against response time

Figure 9 shows the PID Tuner dialog with the initial design. The PI controller is designed in feedback loop of setpoint and disturbance. The controller values for Ki and Kp are determined with Ki=0.1117 and Kp= 0.3723. The derivative value is equal to 0.

Where, Kp is a proportional coefficients and Ki is integral coefficients.

Table 1 shows the computed Integral Absolute Error (IAE) values for PI and PID controller with the equation. The IAE values in the table are the lowest IAE values among the disturbance and set point. Based on the table, it concludes that for PI and PID disturbance Adaptive PI controller has the lowest IAE values as well as for PI and PID setpoint, Adaptive PI controller also has the lowest IAE values

TABLE 1. Controller Simulation Results

Control System	Controller	Types Of Errors	Loops	IAE
Adaptive	PI	Disturbance	IMC	0.048
Adaptive	PID	Disturbance	Minimum ITAE-Rovira (1969), Model:Method 4	0.081
Adaptive	PI	Setpoint	Minimum ISE- Khan and Lehman (1996), Model: Method 1	23.2
Feedforward	PID	Setpoint	Minimum ISE-Wang (1995), Model:Method 1	42.1

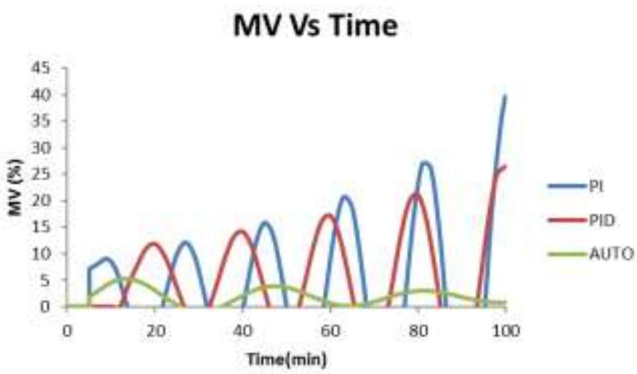

Fig. 10. MV versus time setpoint

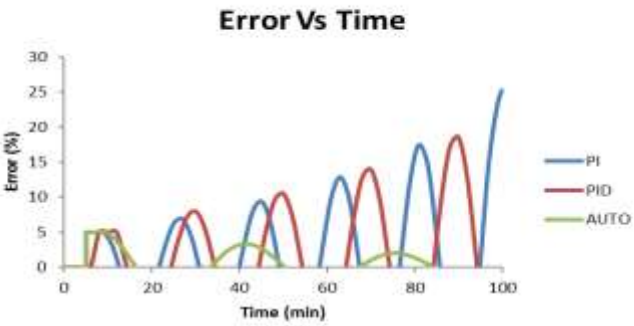

Fig. 11. Error versus time setpoint

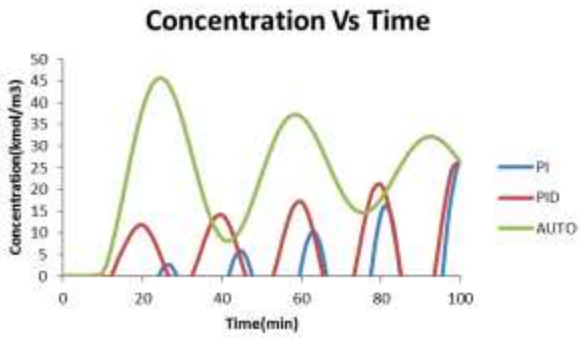

Fig. 12. Concentration versus time

Figure 10, 11 and 12 are the graphs result based on the simulation of the controller which has the lowest IAE values at the present of setpoint change. Figure 12 shows that as the time increases the deviation of the line graph increases. At 25 minute, the auto tune has the highest peak of concentration with 45 kmol/m^3. Based on the Figure 10, the MV of the auto tune control system is lower compare to PI and PID. The amplitude of oscillation of auto tune reduces with time, hence showing a greater robustness and minimizing the effects of the uncertainties present in the system.

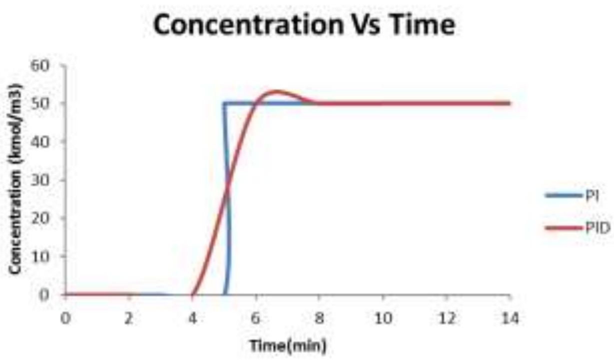

Fig. 13. Concentration versus time disturbance

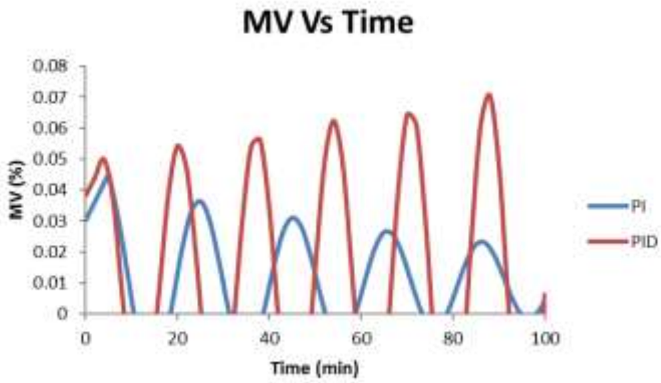

Fig. 14. MV versus time disturbance

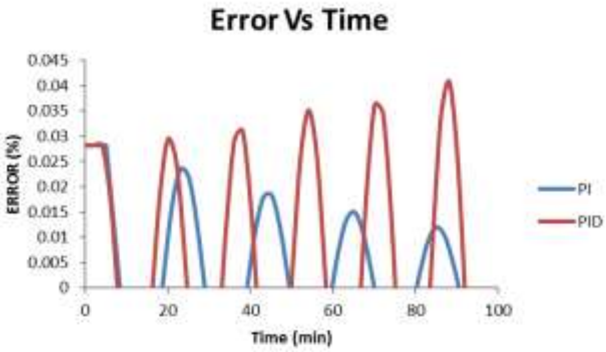

Fig. 15. Error versus time disturbance

The PI and PID controller modelled is tuned by using different kind of control systems with the present of disturbance. The simulation result of Adaptive PI and Feedback PID are shown in figure. Figure 13 shows that through PID controller, the system takes 8 minute to achieve steady state and have peak overshoot of 50.03 kmol/m^3. Based on the Figure 14 and Figure 15, the amplitude MV and error of PI is lower than PID control system. Hence, the most optimum controller system is Adaptive PI because it is providing minimum settling time to reach the set point, reduced oscillations, short rise time and stability in the presence of disturbances.

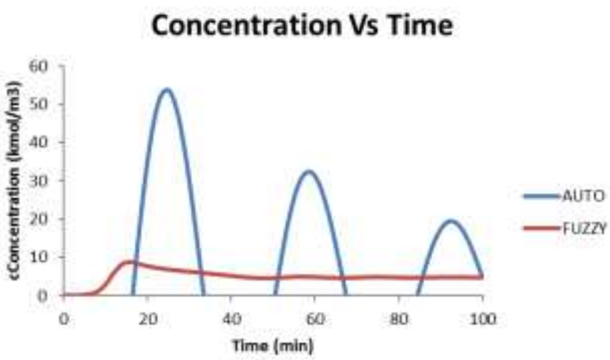

Fig. 16. Concentration versus time using auto tune and fuzzy

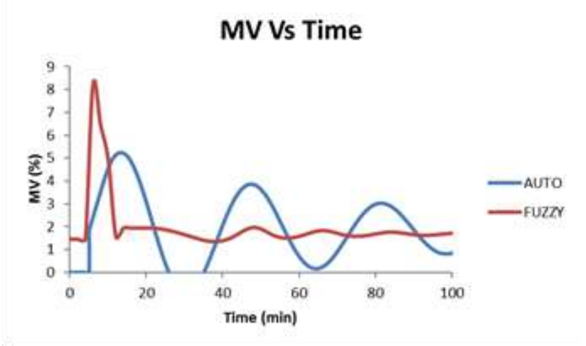

Fig. 17. MV versus time result using auto tune and fuzzy

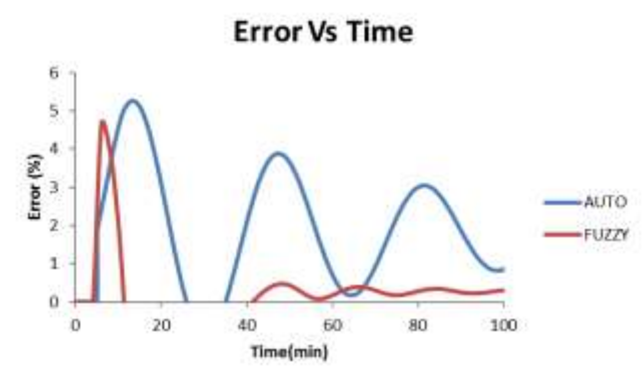

Fig. 18. Error versus time using auto tune and fuzzy

Auto tuned controller gives the best response as compared to other technique.Therefore, auto tuned will be compared with fuzzy logic to determine which one is the best control system. In Figure 16, fuzzy control system shows less overshoot and it also achieves steady state in quick time compare to auto tune. Besides, by referring to Figure 17, fuzzy line is overshoot higher than auto tune at 6 minutes. However, after that the fuzzy line become more stable and the oscillation also reduced. In addition, the percentage error of fuzzy logic controller is lower than auto tune. The percentage error is likely to stabilize near to zero. Therefore, it can be concluded that fuzzy is the best control system for non-isothermal CSTR.

V. Conclusion

At the beginning of the simulation, the advanced control systems such as adaptive control, cascade control, smith predictor and feedforward as well as feedback control have been design for CSTR process. The best controllers must be determined among the various types of controllers. The controllers are compared for each PI and PID when there is a set point change, disturbance and auto tune is introduced in the system. From the result, it was found out that auto tune is a better controller than PI and PID. Therefore, auto tune result is used to compare with the fuzzy logic controller result. In conclusion, the best control system for non-isothermal CSTR is fuzzy logic controller.

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