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Analysis of Conventional controllers for high pressure rated modified CSTR system

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Abstract: The control of chemical reactor is one of the most challenging problems in control process. A Continuous Stirred Tank Reactor (CSTR) is the heart of many processes, its stable and efficient operation is important to the success of an entire process. The CSTR is one of the optional machineries available to mimic and maintain the deep sea conditions such as pressure, temperature, pH etc in the laboratory to study environmental effects. This paper presents the design of suitable conventional controller and tuning methods to optimize the system performance for a hyperbaric reactor system. In environmental CSTR the control of temperature is an absolute challenge due to strong on-line non linearity. The suitable control strategy was explored here to develop the environmental CSTR system for deep sea applications using real time on-line open loop temperature curve. The First Order Plus Dead Time (FOPDT) process model was chosen to derive transfer function from real time on-line system curve at atmospheric pressure and 31^0C temperature condition. Simulation and result comparison is carried out using MATLAB &SIMULINK. Different conventional controllers are examined to optimize the temperature control for environmental CSTR system. The simulation result on the environmental CSTR system is presented to show efficiency of various controllers.

Keywords: Process modeling, PI controller, PID Controller.

I. INTRODUCTION

The continuous stirred-tank reactor (CSTR) is a common ideal reactor type in chemical engineering. The selection of a reaction system that operates in the safest and most efficient manner can be the key to the success or failure of a chemical plant. Here the control of temperature in the high pressure rated environmental Continuous stirred tank reactor (CSTR) where deep sea conditions mimicking is considered. Deep sea is an extremophilic and hostile environment with high pressure, exciting temperature variation, limited food supply and absolute darkness. Although it has been characterized as physically stable environment and several environmental variables pose major challenges to the very basic survival of biological organisms. It is well documented that some of the environmental variables like pressure and temperature affects the biological organisms physiologically and biochemically through the modification in the performance and structure of vital constituents like proteins and lipids. The CSTR is one of the optional methods available to examine the environmental effects associated with the deep sea environment. Since studying the native plants, animals and microbes of deep-sea in-situ conditions is too complicated, we have to overcome technological challenges in conducting biological experiments mimicking deep-sea environment. The most challenging parameters in the deep-sea in-situ conditions are temperature, light and pressure etc . Here a CSTR system has been designed developed and tested to utilize for mimicking deep sea conditions. The problem of controlling the temperature in the environmental CSTR system is considered as a challenging issue, especially for a control engineer corresponding to its nonlinear dynamics because of its high pressure rated reactor vessel which has thick wall material and PTFE liner mounted inside the reactor system to avoid sea water corrosion and that creates temperature oscillation and instability in the system. The nonlinear characteristics of system and their functional parameter change due to high pressure rated reactor design. The need for better control strategies for temperature control of deep-sea CSTR system is to achieve better performance. The system has to be modelled accurately for the design of controller. In this work, it is modelled as a First Order Plus Dead Time (FOPDT) system from real time open loop response [3]. The system is having significant delay due to various reasons in the environmental CSTR.

Generally the system is initially checked with conventional controllers including PI, PID since it is easy to develop and implement. Various methods are available for tuning these controllers, Ziegler Nichols method is one of them.

II. SYSTEM DISCRIPTION

Environmental CSTR system is a new kind of process because it should match with the extreme environment like deep sea, according to specific requirements. Temperature control in the environmental CSTR system for deep-sea condition i.e. mimicking in the reactor is considered as a challenging issue due to its nonlinearity because of its high pressure rating and thick wall material in the reactor system. The steady state simulation of an environmental continuous stirred tank reactor system precious temperature control has been implemented in the developed real time rector system. To avoid corrosion in the reactor system during sea water, PTFE liner has to be mounted inside the reactor system. Nevertheless, it

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induces oscillation and instability of the system and thick reactor vessel compounds this issue further. Therefore, an attempt was made to achieve the precious temperature control in the environmental CSTR mimicking one of the vital deep sea parameter i.e. temperature.

The system used to describe deep sea conditions in the environmental CSTR system includes a high pressure rated double jacketed reactor vessel, multiport serial server, digitally control heater/ chillers system, modem, temperature sensor and PC. The working pressure and temperature, at which any reactor or pressure vessel can be used, will entirely depend upon the design, size and nature of the material used for construction. Since all materials tend to vary their strength according to change in temperature, any pressure rating must be stated in terms of the temperature at which it is applicable. Here selected pressure rate is 5000 psi and temperature rate is -90 ^{0}c to 235 ^{0}C and the volume of reactor vessel for real time experiment is 5L. The PTFE liner has been used to fit inside the reactor vessel. It must be noted, however, that adding a liner will slow the heat transfer rate into the vessel and it may be necessary to adjust the temperature control method to prevent overheating. Refrigeration bath circulators suitable for controlling the temperature and is achieved through circulation of silicon oil in the thermostat bath. The equipment is able to meet the highest demands and this is ensured by the appropriate range of functional components like controller, programmer, temperature sensor, interface as well as extensive safety and warning systems for better performance.

The bath vessel has a volume of 5L and can be emptied via a drain pipe controlled by valve. The simulation model of the system is shown in figure.1.

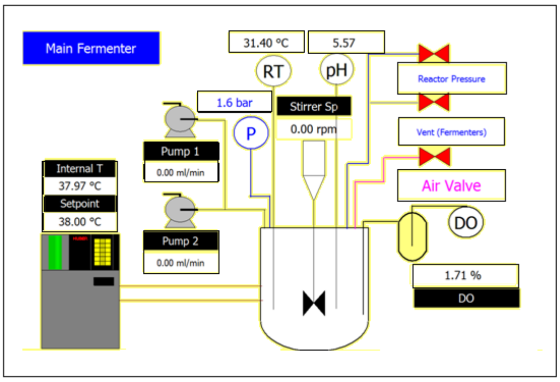

Figure 1. Simulation Model for the System

Considering the delay factors the system is modeled as First Order Plus Dead Time system and the general transfer function model is given below,

$$G(s) = \frac{Ke^{-\tau_d s}}{\tau s + 1}$$

FOPDT process was examined in the presence and absence of PTFE liner in high pressure rated environmental CSTR system. Real time open loop temperature curve has been employed for mathematical model derivation.

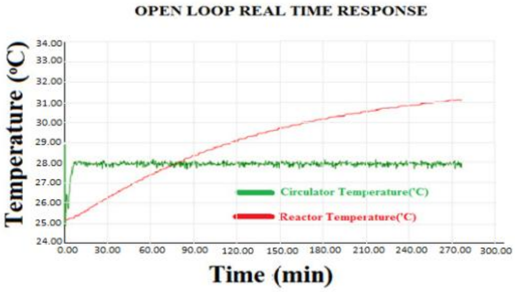

Fig.2 Real time open loop response of environmental CSTR system with PTFE liner.

From this graph we can obtain the following terms,

$$K_p = \frac{\Delta(change\ in\ output)}{\delta(change\ in\ input)} = 0.71654 \qquad (2)$$

T_1 = 11.05105 min
T_2 = 44.20423 min

$$\text{Time constant } (\tau_p) = 1.5(T_2 - T_1) = 49.72977 \qquad (3)$$

$$\text{Time delay} = T_2 - \tau_p = 5.52554 \qquad (4)$$

$$G_p(s) = \frac{0.71654e^{-5.52554s}}{49.72977s + 1} \qquad (5)$$

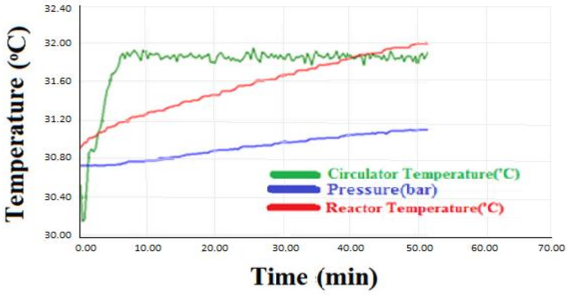

Fig.3. Real time open loop response of environmental CSTR system without PTFE liner.

From this graph we can obtain the following terms,

$$K_p = \frac{\Delta(change\ in\ output)}{\delta(change\ in\ input)} = 0.967 \qquad (6)$$

T_1 = 4.018 min
T_2 = 16.744 min

$$\text{Time constant } (\tau_p) = 1.5(T_2 - T_1) = 19.089 \qquad (7)$$

$$\text{Time delay} = T_2 - \tau_p = 2.345 \qquad (8)$$

$$G_p(s) = \frac{0.967e^{-2.345s}}{19.089s + 1} \qquad (9)$$

III. PI CONTROLLER

PI controller is used in many process industries due to its fast response and quick tuning. The controller will eliminate steady state error resulting in operation of P controller. However, introducing integral mode has a negative effect on speed of the response and overall

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stability of the system. It calculates the error value as the difference between a measured process variable and a desired set-point. The controller tries to minimize the error by adjusting the process control input. PI is simple, robust and widely used in many control applications.
Mathematically

$$u(t) = K_p e(t) + K_p \frac{1}{T_i} \int e(t)dt \qquad (10)$$

Ziegler- Nichols closed loop method is used here for the tuning of PI controller (with and without PTFE liner). The settings for PI controllers are determined directly from Ku and Pu according to the rules summarized in table 1.

Table 1
Z-N closed loop tuning rules for PI controller.

Control type	K_p	τ_i	K_i
PI	$\frac{K_u}{2.2}$	$\frac{P_u}{1.2}$	$\frac{K_p}{\tau_i}$

IV. PID CONTROLLER

A typical structure of a PID control system is shown in fig.4. The error signal e(t) is used to generate the proportional, integral, and derivative actions, with the resulting signals weighted and summed to form the control signal u(t) applied to the plant model. A standard PID controller structure is also known as the ‘‘three-term” controller. The proportional, integral, and derivative terms are summed to calculate the output of the PID controller.

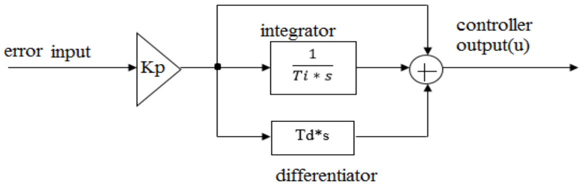

Fig.4. PID control system.

In process industries, PID controller is used to improve both the steady state as well as the transient response of a process plant.
Mathematically,

$$u(t) = K_p e(t) + K_p \frac{1}{T_i} \int e(t)dt + K_p T_d \frac{d}{dt} e(t) \qquad ($$

The gain values of PID controllers for the environmental CSTR system using Ziegler Nichols closed loop tuning (with and without PTFE liner) are obtained and settings for PID controllers are given in the table below

Table 2
Z-N closed loop tuning rules for PID controller.

Control type	K_p	τ_i	K_i	τ_d	K_d
PID	$\frac{K_u}{1.7}$	$\frac{P_u}{2}$	$\frac{K_p}{\tau_i}$	$\frac{P_u}{8}$	$K_p * \tau_d$

V. RESULT AND DISCUSSION

The simulations for conventional control mechanisms discussed above were carried out in SIMULINK & results have been obtained. Both the servo and regulatory responses of above controllers were observed and compared. The results are as shown below. Fig 5& 6 shows the comparison of servo & regulatory responses of environmental CSTR with PTFE liner. Fig 7& 8 shows the comparison of servo & regulatory responses of environmental CSTR with PTFE liner

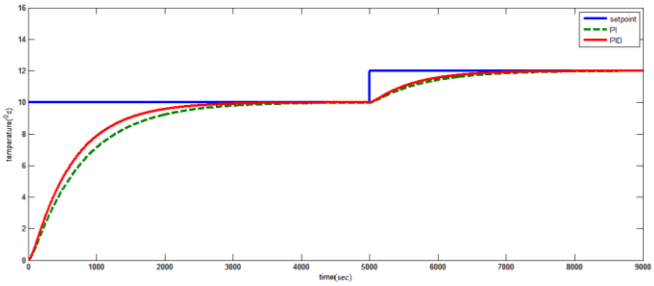

Fig.5. Servo response of PI and PID controller with PTFE liner.

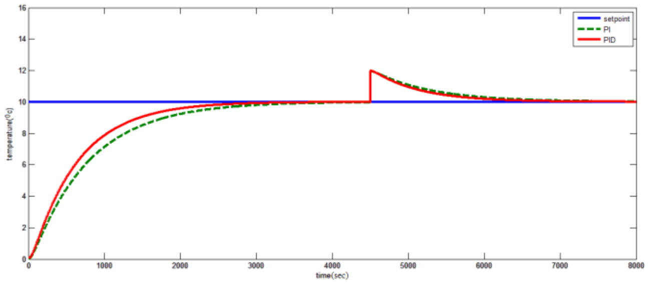

Fig.6. Regulatory response of PI and PID controller with PTFE liner.

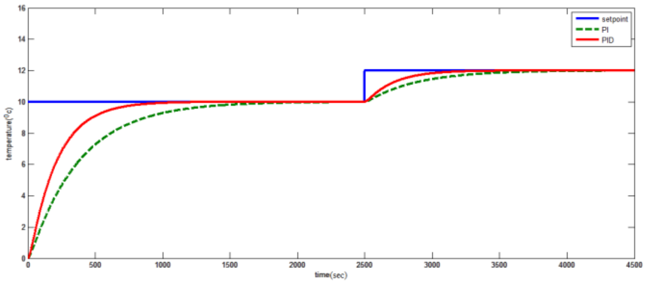

Fig.7. Servo response of PI and PID controller without PTFE liner.

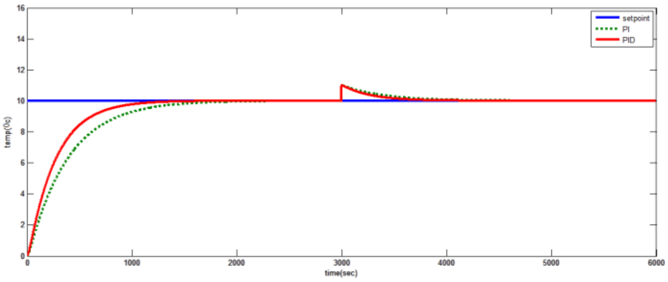

Fig.8. Regulatory response of PI and PID controller without PTFE liner.

The performances of controllers are also examined using ISE and IAE and their values for PID controller are less compared to PI controller in the entire operating region. The performance indices in terms of ISE and IAE for servo and regulatory response are also shown in table 3 and 4.

Table.3.
Performance comparison (SERVO response)

	Controller	IAE	ITAE
With PTFE liner	PI	9734	2060.5
	PID	7974	1561.6
Without PTFE liner	PI	4679	1490.6
	PID	2624	655.5

Table.4.
Performance comparison (REGULATORY response)

	Controller	IAE	ITAE
With PTFE liner	PI	9630	1494.7
	PID	7946	1135
Without PTFE liner	PI	4290	1119.9
	PID	3050	658.7

VI. CONCLUSION

For the non linear process a PI &PID controllers are designed. The performance is tested using MATLAB. The comparison of PID controller with PI controller is done and the experimental results prove that the response is smooth for both servo and regulatory changes for these controllers. It is concluded that PID controller is suited to control the temperature of high pressure rated modified CSTR system when compared to PI controller

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