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Comparative Analysis of Temperature Controllers for High Pressure Rated Modified CSTR system

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ABSTRACT: 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 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. A suitable control strategy was explored 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^{0}C temperature condition. Simulation and result comparison is carried out using MATLAB &SIMULINK. Different 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 &PID Controller. FUZZY PID Controller

I.INTRODUCTION

The continuous stirred-tank reactor (CSTR) is a common ideal reactor type in chemical engineering. Chemical kinetics and reactor design are at the heart of producing almost all industrial chemicals. 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 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 a physically stable environment, 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 machineries available to examine the environmental effects associated to the deep sea environment. Since studying the native plants, animals and microbes of the 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. 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 embedded 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 precious temperature control in the special kind of deep-sea CSTR system process control in order 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

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from the real time open loop response [3]. The system is having significant delay due to various reasons in the environmental CSTR.

Generally the systems are initially checked with conventional controllers including PI,PID since it is easy to develop and implement. Various methods are available for tuning these controllers. If the response is not satisfactory advanced controllers are considered. When the system is non-linear and with significant delay conventional controllers cannot give satisfactory result. Fuzzy PID controller is a suitable alternative in such case. It can deal with non-linear systems efficiently.

II.SYSTEM MODEL

The environmental CSTR system is a new kind of instrument 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 nonlinear dynamics 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 embedded inside the reactor system.. 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 are of externally connected appliances and thermoregulation is achieved through circulation of silicone 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.

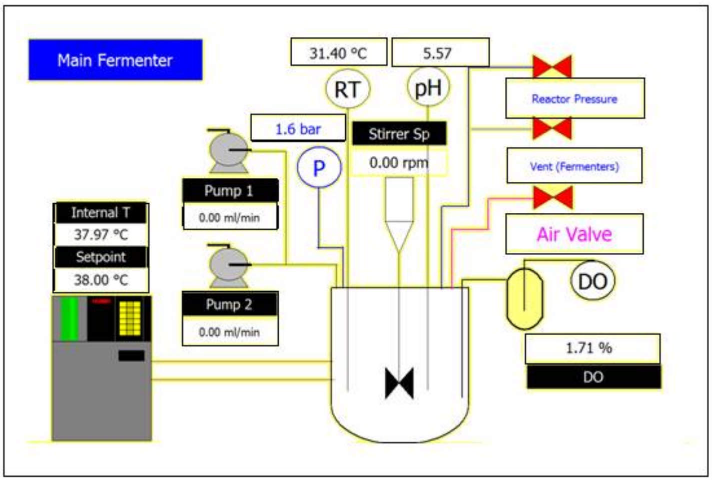

Figure 1. Simulation Model for the System

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

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

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.

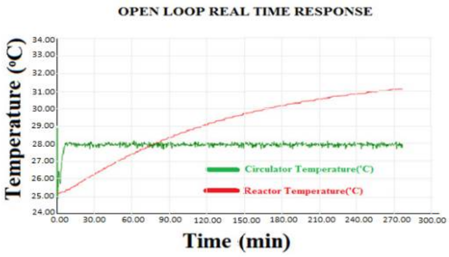

Fig.2 Real time open loop response of environmental CSTR system with PTFE liner.

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

Time constant (τ_p) = 1.5($T_2 - T_1$) = 49.72977 (3)
Time delay = T_2 - τ_p =5.52554 (4)

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

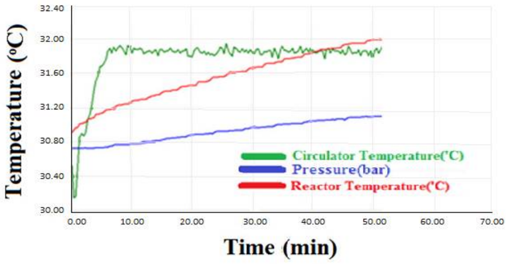

Fig.3. Real time open loop response of environmental CSTR system without PTFE liner.

From this graph we can obtain the following terms,

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

$T_1 = 4.018$ min
$T_2 = 16.744$ min

Time constant (τ_p) = 1.5($T_2 - T_1$) = 19.089 (7)
Time delay = T_2 - τ_p =2.345 (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. It calculates the error value as the difference between a measured process variable and a desired set-point. The PI 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.4.9 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. The proportional, integral, and derivative terms are summed to calculate the output of the PID controller.

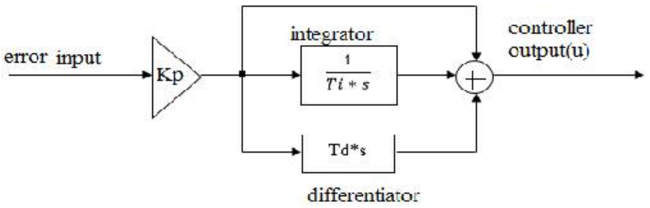

Fig.4. PID control system.

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Mathematically,

$$u(t) - K_p e(t) + K_p \frac{1}{T_i} \int e(t)\,dt + K_p T_d \frac{d}{dt} e(t) \qquad (11)$$

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. FUZZY PID CONTROLLER

FLC can cover much wider range of operating conditions than PI &PID and can operate with noise and disturbances of different nature. Fuzzy control uses a list of rules than complicated mathematical expressions. Based on the process knowledge, an intelligent control technique that is Fuzzy PID Control is discussed. The structure of fuzzy PID controller is shown in Fig 5. It mainly consists of two parts, one is the conventional PID controller and the other is fuzzy logic controller. In this work, two input and three output fuzzy PID controller is designed. The inputs are the error and the error rate (change in error) and outputs are the values of Kp, Ki and Kd. Variable PID controller adds the output value of the fuzzy controller and default PID values.

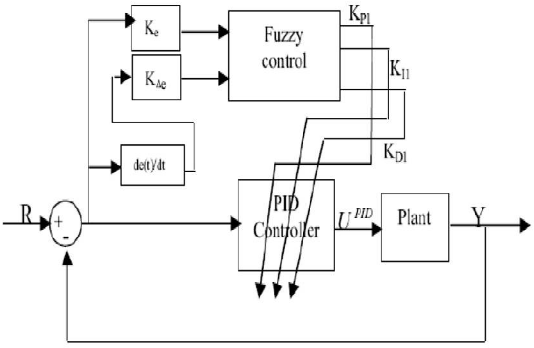

Fig.5.Structure of Fuzzy PID

The FLC is adding to the conventional PID controller to adjust the parameters of the PID controller on-line according to the change of the signals error and change of the error. Now the control action of the PID controller after self tuning can be describing as:

$$U_{PID} = K_{p2}e(t) + K_{i2}\int edt + K_{d2}\frac{de(t)}{dt} \qquad 15)$$

Where K_{p2}, K_{i2} and K_{d2} are the new gains of PID controller

Where K_{p1}, K_{i1}, and K_{d1} are the gains outputs of fuzzy control, which are varying online with the output of the system under control. Where K_P, K_i , and K_d are the initial values of the conventional PID.

For the system under study the universe of discourse for both e(t) and De(t) may be normalized from [-1.5,1.5], and the linguistic labels are (Negative Big, Negative Medium, Negative Small, Zero, Positive Small, Positive Medium, Positive Big), and are referred to in the rules bases as (NB, NM, NS, ZE, PS, PM, PB) and the linguistic labels of the outputs are (Zero, Medium Small, Small, Medium, Big, Medium Big, Very Big) and referred to in the rules bases as (Z, MS, S, M, B, MB, VB).

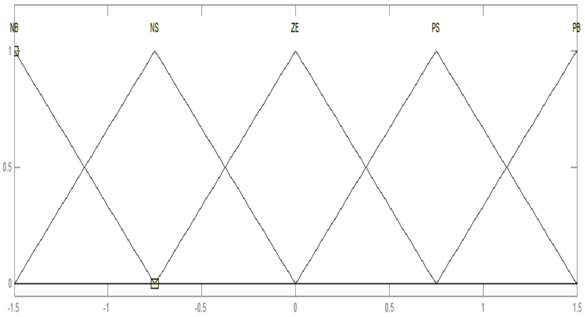

Fig.6. membership function of inputs (e,Δe)

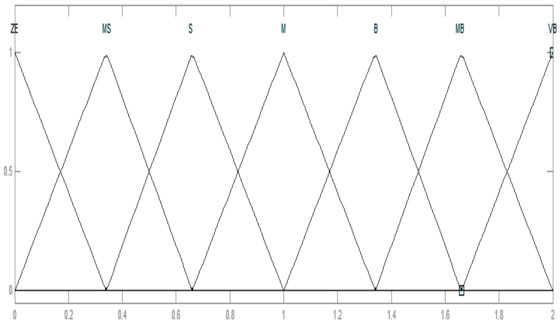

Fig.7. Membership functions of outputs (K_{p1}, K_{i1}, K_{d1})

Table.3. Rule base for determining K_{p1}

Δe e	NB	NS	ZE	PS	PB
NB	VB	VB	VB	VB	VB
NS	B	B	B	MB	VB
ZE	ZE	ZE	MS	S	S
PS	B	B	B	MB	VB
PB	VB	VB	VB	VB	VB

Table 4.Rule base for determining K_{i1}

Δe e	NB	NS	ZE	PS	PB
NB	M	M	M	M	M
NS	S	S	S	S	S
ZE	MS	MS	ZE	MS	MS
PS	S	S	S	S	S
PB	M	M	M	M	M

Table 5. Rule base for determining K_{d1}

Δe e	NB	NS	ZE	PS	PB
NB	ZE	S	M	MB	VB
NS	S	B	MB	VB	VB
ZE	M	MB	MB	VB	VB
PS	B	VB	VB	VB	VB
PB	VB	VB	VB	VB	VB

VI. RESULT AND DISCUSSION

The simulations for different 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.

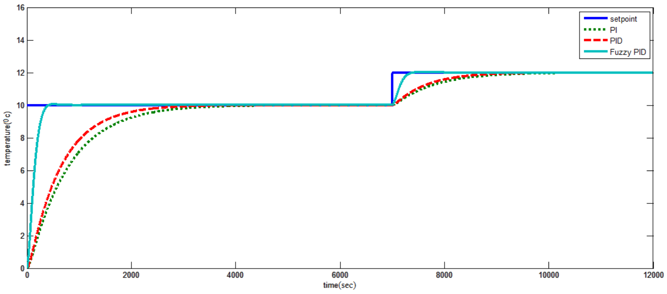

Fig.8. Servo response of controller with liner

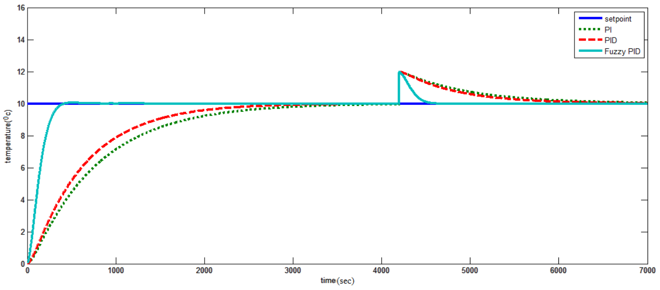

Fig.9.Regulatory response of controllers with liner

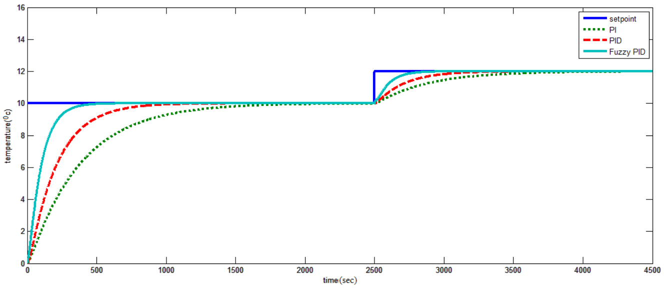

Fig.10. Servo response of controllers without liner.

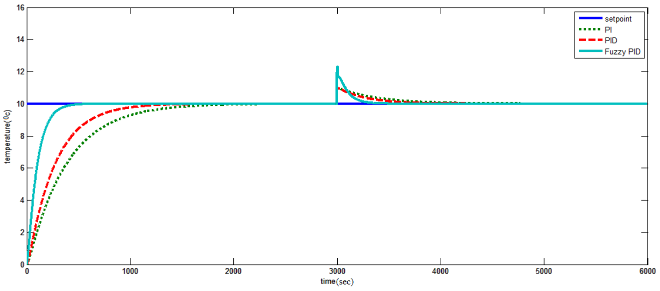

Fig.11. Regulatory response of controllers without liner.

The performances of controllers are also examined using ISE and IAE and their values for FUZZY PID controller is less compared to both PI & PID 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 6 and 7.

Table.6. Performance comparison (SERVO response)

	Controller	IAE	ITAE
With PTFE liner	PI	9734	2060.5
	PID	7974	1561.6
	FUZZY PID	1700	868.9
Without PTFE liner	PI	4679	1490.6
	PID	2624	655.5
	FUZZY PID	1241	445

Table.7. Performance comparison (REGULATORY response)

	Controller	IAE	ITAE
With PTFE liner	PI	9630	1494.7
	PID	7946	1135
	FUZZY PID	1700	549
Without PTFE liner	PI	4290	1119.9
	PID	3050	658.7
	FUZZY PID	1242	593

VI.CONCLUSION

For non linear process a PI, PID & FUZZY PID controllers are designed. The performance is tested using MATLAB. The comparison of FUZZY PID controller with conventional 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 FUZZY PID controller is suited to control the temperature of high pressure rated modified CSTR system when compared to conventional controller.

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