Fuzzy based Temperature Controller for High Pressure Rated Modified CSTR system

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Abstract: The Continuous Stirred Tank Reactor (CSTR) is the important topic in process industries, its stable and efficient operation is important to the success of an entire process. It 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. 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: High pressure rated CSTR system, Process modelling, PID Controller, Fuzzy PID Controller.

I. INTRODUCTION

The control of temperature of a continuous stirred-tank reactor (CSTR) is the challenging issue 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 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 changes due to high pressure rated reactor design. To achieve better performance it is necessary to control the temperature in the deep sea CSTR. The system modelled accurately for the design of controllers. In this work, it is modelled as a First Order Plus Dead Time (FOPDT) system from the real time open loop response [3]. The system is having significant delay due to various reasons in the environmental CSTR.

One of the most important controllers both in academic and industrial application is PID. Easy implementation of PID controller made it more popular in control system application. Basically PID tries to correct the error between measured outputs and desired outputs of the process in order to improve the transient and steady state response as much as possible. Various methods are available for tuning the conventional controller, Ziegler Nichols method is one among them and is used here for controlling the temperature.

Fuzzy controlled system models don't require any certain model for implementation of system under consideration. Success of the fuzzy logic, which based on the approximate reasoning instead of crisp modelling assumption, remark the robustness of this method in real environment application.

II. SYSTEM DESCRIPTION

Continuous Stirred Tank Reactor (CSTR) is an important topic in process control and Environmental CSTR system is a new kind of instrument, which should match with the extreme environment like deep sea, according to specific requirements. Temperature control in the environmental CSTR system is considered as a challenging issue due to its nonlinear behaviour. To avoid corrosion in the reactor system during sea water, PTFE liner has to be embedded inside the reactor system. Nevertheless, it 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 are of externally connected appliances and thermoregulation 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.

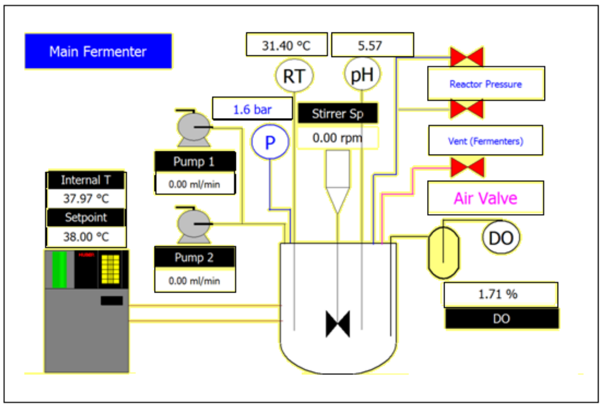

Figure 1 Simulation Model for the System

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

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

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.

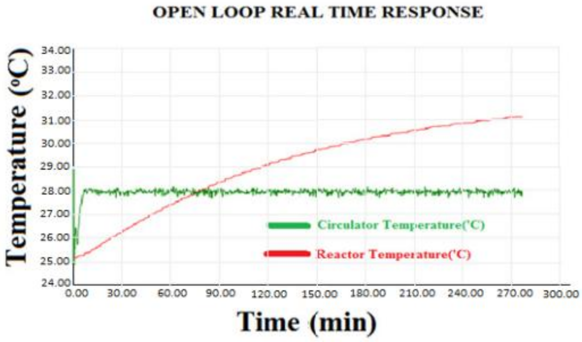

Fig.2 Real time open loop response of environmental CSTR system with PTFE liner

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)

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

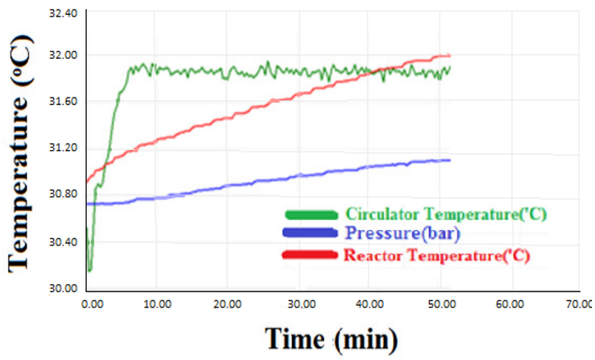

Fig.3. Real time open loop response of environmental CSTR system without PTFE liner

From this graph we can obtain the following terms,

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

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.PID CONTROLLER

In process industries, PID controller is used to improve both the steady state as well as the transient response of a process plant. In a closed loop control system, the controller continuously adjusts the final control element until the difference between reference input and process output is zero.

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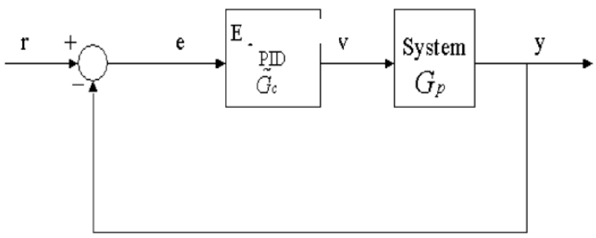

Fig.4. PID controller

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 1 Z-N closed loop tuning rules for PID controller.

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

IV.FUZZY PID CONTROLLER

Fuzzy controllers are more robust than conventional controllers like PI, PID controllers because 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. The objective is to find the fuzzy relations among Kp, Ki, Kd, error and error rate. With continuous testing, the three output parameters are adjusted so as to achieve good stability. Variable PID controller adds the output value of the fuzzy controller and default PID values.

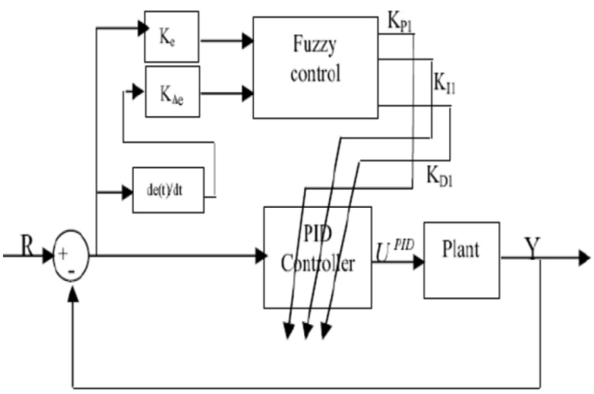

Fig.5.Structure of Fuzzy PID

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).

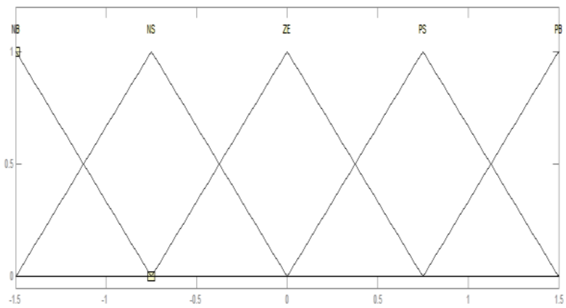

Fig.6. membership function of inputs (e,Δe)

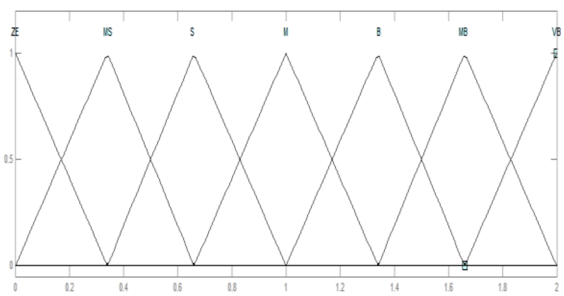

Fig.7. Membership functions of outputs (K_{p1}, K_{i1}, K_{d1})

TABLE.2. 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 3 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 4 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

V. RESULT AND DISCUSSION

The simulations for conventional PID control mechanism and FUZZY PID are 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& 9 shows the comparison of servo & regulatory responses of environmental CSTR with PTFE liner. Fig 10&11 shows the comparison of servo & regulatory responses of environmental CSTR without PTFE liner

The performances of controllers are also examined using ISE and IAE and their values for FUZZY PID controller is less compared to conventional PID controller in all the operating region. The performance indices in terms of ISE and IAE for servo and regulatory response are also shown in table 5 and 6.

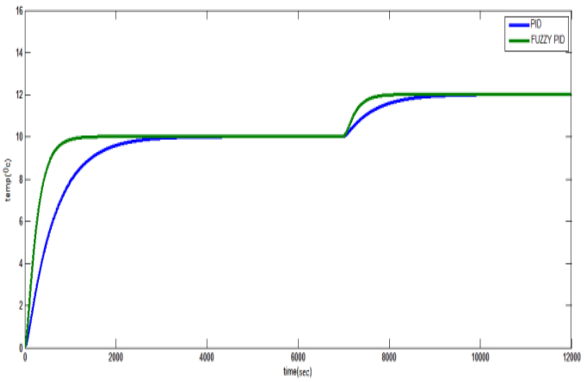

Fig.8. Servo response of PID and FUZZY PID controller with PTFE liner

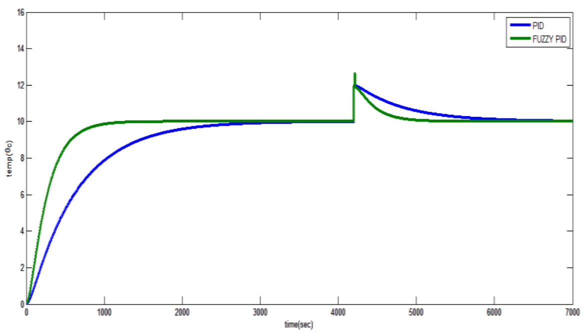

Fig.9. Regulatory response of PID and FUZZY PID controller with PTFE liner

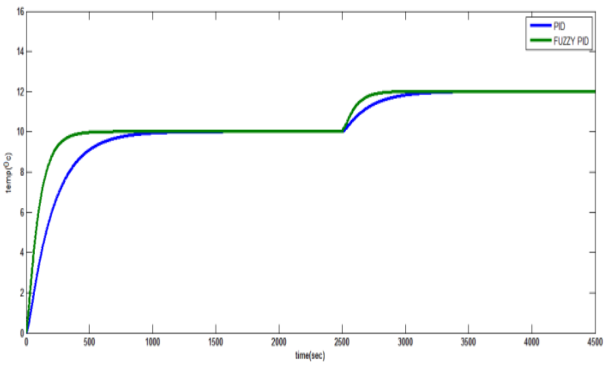

Fig.10. Servo response of PID, FUZZY PID controller without PTFE liner

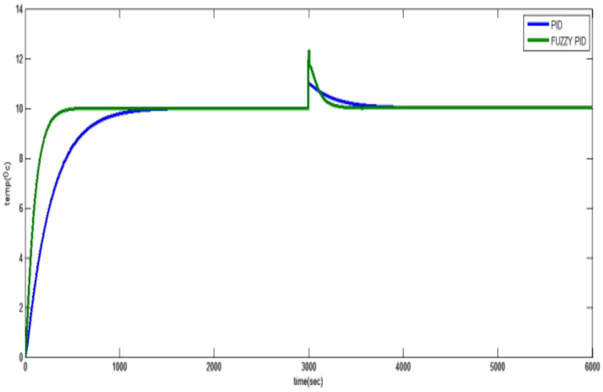

Fig.11. Regulatory response of PID, FUZZY PID controller without PTFE liner

TABLE.5 Performance comparison (SERVO response)

	Controller	IAE	ITAE
With PTFE liner	PID	7974	1561.6
	FUZZY PID	1700	868.9
Without PTFE liner	PID	2624	655.5
	FUZZY PID	1241	445

TABLE.6. Performance comparison (REGULATORY response)

	Controller	IAE	ITAE
With PTFE liner	PID	7946	1135
	FUZZY PID	1700	549
Without PTFE liner	PID	3050	658.7
	FUZZY PID	1242	593

VI. CONCLUSION

For non linear process PID & FUZZY PID controllers are designed. The performance is tested using MATLAB. The comparison of FUZZY PID controller with PID 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 PID controller.

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