Design and Implementation of Controller for Ph Process at Elevated Pressure

S. Vinodha, K. Thiruppathi, P. Lakshmi

Abstract: *This paper describes the modeling and control of a pH neutralization process and compares the traditional, fuzzy logic and Genetic Algorithm (GA) optimization methods for the novel deep sea microbial instrument at elevated pressure. National Institute of Ocean Technology (NIOT) has designed, developed and patented a novel instrument to mimic deep sea conditions in laboratory for deep sea microbial exploration. Controlling pH in the novel deep sea conditions mimicking laboratory system is complicated, because of high salinity, temperature stimulus, high pressure operation, and its non-linearity. To address the pH control issues a systematic real time experimental model was designed developed, implemented and analyzed. The simulation results shows that the proposed controller technique is effective in tracking set point and has resulted in a minimum value of the Integral Square Error, peak overshoot and minimum settling time as compared to conventional methods. The experimental results show that the model accuracy and the GA and fuzzy logic controller performance is superior then the other control methods and it matches favorably with the simulation results.*

Index Terms: *Fuzzy logic control, Genetic algorithm, Novel deep sea microbial system, Real time pH control.*

I. INTRODUCTION

The microbes living in extreme environments (deep sea) are known to produce various unique bio-active metabolites, but very limited progress has been made till date because of unavailability of readily usable system to explore the deep sea microbes. Technology advancement has now enabled us to explore deep sea living areas in order to harness the full potential from them. The term deep sea microbes refer to those which are thriving arbitrarily below 200 m depth in the ocean. These microbes survive in extremely harsh conditions, such as hundreds of bar pressure, less oxygen (Ziebis et al. 2012, Owens et al. 2017), dark and extreme cold or hot environment. Mimicking several deep sea environmental variables, like temperature, pressure, pH and DO, etc. poses major challenge in studying those creatures in an artificial environment.

pH is one of the crucial parameter that exhibits a large scale impact on marine ecosystems according to Kroeker *et al.* (2013). Industrialists are able to develop an efficient and interesting new development with the help of noise free new generation hardware. The corrosive and high pressure conditions associated with deep sea environments demands the special pH sensors to tolerate these conditions. A special pH probe (140 bar pressure and 130^{o}C temperature rated) is employed for the first time in deep sea conditions mimicking experiment and exploration. Many researchers are reported the pH control at normal laboratory conditions and few researchers addressed at extreme conditions such as ice environment. The pH control at elevated pressure is not addressed till now. So, this work focused more on the control of pH at elevated pressure condition. Process dead time is also planned to reduce by implementing a suitable mixing system at elevated pressure.

II. EXPERIMENTAL SETUP FOR pH CONTROL

The schematic, Graphical User Interface (GUI) diagram and experimental setup are shown in Figures 1, and 2 respectively. Deep sea conditions mimicking laboratory system consists of two main units, an apparatus console and software control console. The system contains two high pressure rated (350bar) double jacketed reactor vessels, atop multiport serial server, safety rupture disc module, computer control solenoid valves for pressure control and regulation, 400bar rated pressure sensor, hermetically sealed magnetic stirrer for uniform mixing, PT 100 temperature sensors, 140bar pressure and 130^{o}C temperature rated pH probe, 400bar pressure rated computer controlled positive displacement acid/base dosing pumps, pressure controller, pH and temperature controllers, computer controlled chiller cum heater system, modem and a personal computer installed with Delphi 6 software for process control and communication. The reactor vessel used for real time experiment is of 3L volume with 350bar pressure and -20^{o}C to 275^{o}C temperature rated. Chiller cum heater bath circulator is used to control the reactor temperature through circulation of high density silicon oil in the thermostat bath. The equipment is able to meet the highest demand which has ensured by using appropriate range of functional components like controller, programmer, temperature sensor, RS-485 interface as well as an extensive safety and warning system for better performance. The chiller cum heater bath vessel has a volume of 5L and can be emptied via a valve controlled drain pipe.

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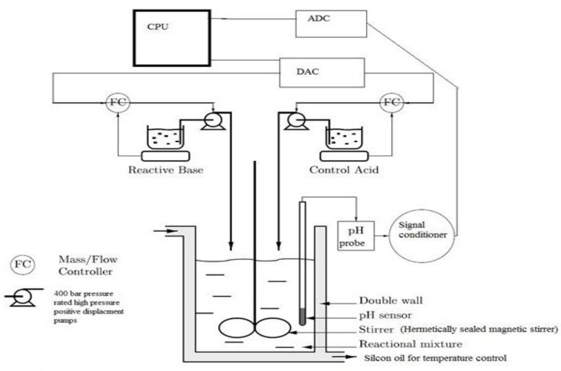

Figure 1 Schematic diagram of system model and its control components

Figure 2 Experimental setup of deep sea conditions mimicking laboratory system

The multiport industrial serial server (SE5008) is a gateway between Ethernet (TCP/IP) and RS-485 communications. It allows almost any serial device to be connected to a new or existing Ethernet network. Most of pH electrodes are not accurate due to influence of change in temperature. The errors from changes in electrode sensitivity, due to changes in temperature can be corrected by temperature compensation technique according to Yokogawa (2009). Automatic Temperature Compensator (ATC) receives a continuous signal from a temperature element and it is automatically corrects the pH value based on the temperature of the solution.

Figure 3 shows the real time temperature compensation of pH process in the system. The pH of any solution is a function of its temperature as reported by Niedrach (1980). Electrode output voltage changes linearly with respect to change in pH value and the temperature of the solution determines the slope of the graph.

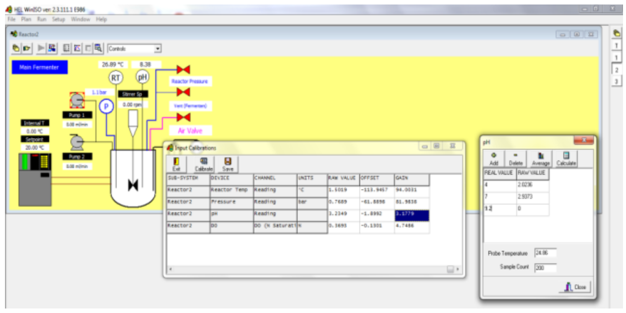

Figure 3 ATC pH probe calibration tool in the deep sea conditions mimicking laboratory system

III. MODEL IDENTIFICATION

The identification of transfer function for pH process is obtained from the real time system open loop data. In this study, model free method is used for system analysis and design, because of the availability of physical system. The high pressure rated acid/base injection positive displacement pumps are used to plot the open loop reaction curve of the deep sea conditions mimicking laboratory system. The initial reactor volume is kept at 3L and stirrer speed at 300rpm. High concentration (1 Molar) of a strong acid (HCl) and strong base (NaOH) are used for the real time experiments at elevated pressure (100bar) and room temperature (30^{o}C). The sampling period is considered as one second.

The manipulated variable is acid/base (u_1) injection using high pressure rated positive displacement pumps and the controlled variable is pH value of the reactor (y_1). The transfer function of the system is calculated experimentally from the open loop response of the process. The experiments are repeated 3 more times to get the reliable open loop data. The reactor pressure and temperature value is kept at 100bar and 30^{o}C respectively. The pH value is changed from 7 to 9 as per the National Institute of Ocean Technology (NIOT) requirements for microbial explorations. The necessary open loop manipulated and controlled variables are logged to identify system transfer function. The open loop response of reactor pH value is shown in the Figure 4 and 5.

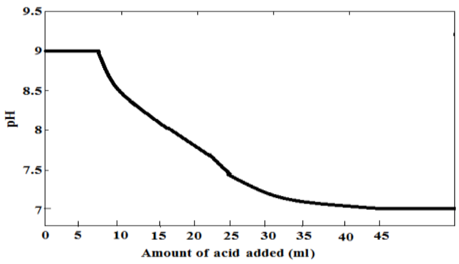

Figure 4 Open loop response of the real time system-Acid response

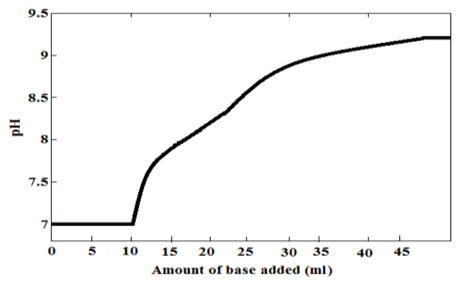

Figure 5 Open loop response of the real time system-Base response

The process transfer function for acid is obtained as,

$$G(s) = \frac{0.276\, e^{-5.005s}}{3.2s+1}$$

The process transfer function for base is obtained as,

$$G(s) = \frac{0.346\, e^{-5.500s}}{4.7s+1}$$

IV. CONTROLLER DESIGN

This section describes the procedures followed in attempting to design a controller for the deep sea conditions mimicking system. Many researchers have used the performance of a PI controller as a benchmark for the pH process. In this work, the PI controller is used to achieve the requirements. The de-facto tuning rules are those developed by Ziegler & Nichols (1942). There are other important rules developed by Cohen & Coon (1953). The Ziegler Nichols and Cohen-Coon method will give better values for k_p and τ_i only when the quarter decay ratio is less than 1, that is the ratio between the delay time and the time constant of the system is ≤1 ($\frac{\tau_d}{\tau} \leq 1$). But for the deep sea conditions mimicking laboratory pH process the quarter decay ratio is $\frac{\tau_d}{\tau} = 1.56$. So, it is clear that these tuning methods cannot give satisfactory values for k_p and τ_i. In this study, an attempt is made to use minimum ISE, ISTSE, ISTES tuning methods for the PI parameter tuning (Aidan 2000) to achieve the requirements.

V. RESULTS AND DISCUSSION

a. Simulation Results

In this section the PI, GA-PI and FLC based pH control process simulation results are presented for the system. The operating point for pH process in the laboratory system is chosen 7 to 9 as per the requirements. The system pressure is kept at 100bar and temperature is fixed at 30^{o}C for this simulation study. The minimum ISTES tuned PI control method takes 48 minutes to reach set point. In the GA-PI control method, the set point is reached at 32nd minute. In FLC control method, the set point is reached at 30th minute. FLC shows better performance in terms of oscillations and settling time than the other control methods.

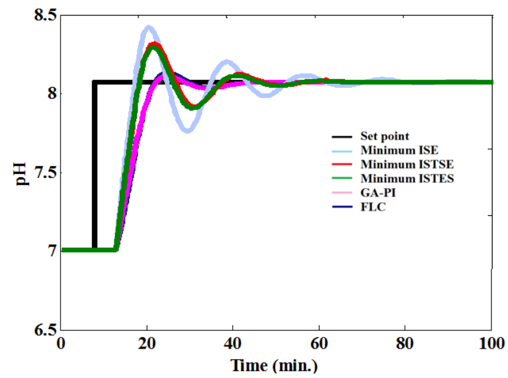

Figure 6 Simulation - pH response - PI, GA-PI and FLC

Subsequently an analysis is made with respect to overshoots and undershoots to identify the best control method. In the minimum ISE tuned PI control method the overshoot and under shoot value is 44%, which is higher than the other control methods. In the minimum ISTSE and ISTES tuned PI control method the overshoot/undershoot value is 24% and 23% respectively. In the GA-PI and the FLC methods the overshoot and undershoot value is less than 5%. Another important requirement of the deep sea conditions mimicking laboratory system pH control process is interaction with other parameters, which is also nullified by employing ATC in the system.

b. Experimental results

The real time experiment results for the minimum ISTES tuned PI and GA-PI control methods are presented in this section. The real time experiments are conducted using the deep sea conditions mimicking laboratory system available at NIOT, Chennai. Based on the simulation results, the real time closed loop experiments for the pH process is conducted at fixed temperature (30^{o}C) and elevated pressure (100bar). Subsequently the real time experiments are executed for the best performer of minimum ISTES tuned PI and GA-PI control methods.

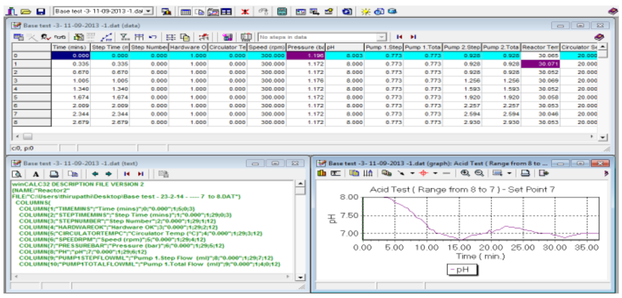

Figure 7 Real time results of minimum ISTES control method for pH value 8 to 7

Based on the simulation result the best performers such as minimum ISTES tuned PI and GA-PI control methods are chosen for real time experiments to realize the requirements. A real time pH

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control experiment is carried out using1Molar HCl (acid) and 1Molar NaOH (base). In the closed loop experiment, the set point is changed from 8 to 7 and executed for 36 minutes. The response of the real time system is shown in Figures 7. From the results, it is observed that there is a 20% overshoot and 18% undershoot in the first cycle and then it settles to the set point. It is further observed from the real time response, the process variable (pH value) starts changing after a small delay which is associated with the process. Initially it oscillates between 6.8 and 7.2 and around 34th minute it settles to the final value without any oscillation as shown in Figure 7.

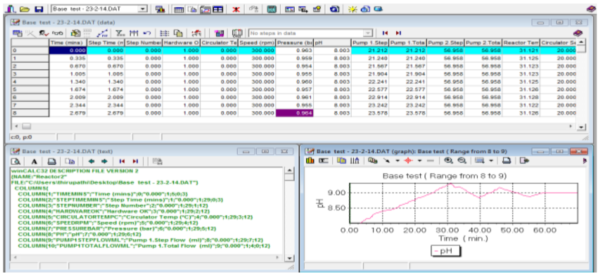

Figure 8 Real time results of minimum ISTES control method for pH value 8 to 9

In the 2nd experiment, the set point is changed from 8 to 9 and it's carried out for 70 minutes. The real time response is shown in Figures 8. From the response, observed a transportation delay and later it shows an oscillation between pH value of 8.85 and 9.3. Around 60th minute it settles to the final value without any oscillation as shown in Figure 8.

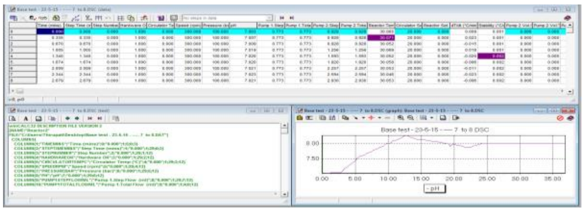

Figure 9 Real time results for GA-PI control method

In the 3rdexperiment, the set point is changed from 7 to 8 and it's carried out for 36 minutes. The real time response is shown in Figures 2.16 and 2.16a. From the response, observed around 3 minutes transportation delay and later it shows an oscillation between pH value of 8.25 and 7.83. The final value is tracked around 25th minute without any oscillation as shown in Figure 9. The real time experiments are carried out only for the Minimum ISTES tuned PI and GA-PI control methods. It is clear from the results that the real time experiment is following the simulation results, which confirms the effectiveness of the models and its dynamic representation of the system. It is clear from the above results that the GA-PI control method performs better than the PI control method. GA-PI control method settles much faster with less oscillation compared with other control methods and the settling time is around 25 minutes. The real time experiment for the FLC method is not carried out due to the unavailability of hardware in the present system. The FLC hardware system proposal for the deep sea conditions mimicking laboratory system is submitted to the necessary authority for the approval and the same will be realized after commissioning of the FLC hardware. The performance indices values for the simulation and real time results are tabulated in Table 1 and 2 respectively. In the GA-PI control method, the error values (IAE, ISE) and settling time are significantly reduced in comparison with the minimum ISTES tuned PI control method.

Table 1 Performance indices & settling time values for various controllers

Types of controller	IAE	ISE	Settling time (Min.)
Minimum ISE tuned PI controller	93.880	463.200	68.00
Minimum ISTSE tuned PI controller	80.630	472.900	54.00
Minimum ISTES tuned PI controller	79.790	443.330	48.00
GA-PI controller	73.714	442.600	35.00
FLC	**73.070**	**426.340**	**27.00**

Table 2 Performance indices & settling time

Types of controller	IAE	ISE	Settling time (min.)
Minimum ISTES tuned PI controller	84.0	493.7	60.0
GA-PI controller	**72.4**	**432.3**	**25.0**

VI. CONCLUSION

In this study, the transfer function is derived from the open loop response. Various control methods like PI, GA-PI and FLC methods are simulated at elevated pressure condition and analyzed to recognize a suitable control method for deep sea conditions mimicking laboratory system operation. From the simulation studies it's clearly observed, the minimum ISTES tuned PI control method performes faster than the Minimum ISE, ISTSE methods. Hence, GA is used for the minumum ISTES tuned PI control method. The experimental results shows that the GA-PI control method is capable of fast set point tracking and minimum error values in comparison with ISTES tuned PI control method. The real time experiment result follows the simulation result, thereby confirming the effectiveness of the model and the dynamic representation of the system. The simulation results shows that the GA-PI and FLC control method gives fast set point tracking and minimum error values in comparison with various tuned PI control methods. Finally the requirements of the deep sea conditions mimicking laboratory system pH process are achieved.

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