International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075, Volume-8 Issue-10, August 2019

Acidic Control of a Chemical Plant Implementing Non Linear Controllers

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Abstract: ***This research work concentrates on developing a non linear control technique using PID control, Fuzzy Logic controller and SMC (Sliding Mode Controller) for acidic control of a chemical plant. This control involves (Variable Structure Control) VSC control. The acidic control process includes a prototype model. This model has two inlets to the sample liquid. The two inlets supply acid and alkaline liquids into a Continuous Stirred Tank Reactor [CSTR]. Both the inflows are controlled in proper proportions, which help to maintain the desired pH of the system. The pH neutralization process is a non linear process; hence VSC serves as a better solution. One type of VSC is the Sliding Mode Control which is applied to this system. Apart from this VSC, both PID control and fuzzy control are incorporated on the same process and the results are furnished. SMC suffers a problem called chattering, but provides reliable results when compared to PID and Fuzzy Logic Controller. This research is done using LabVIEW Software, Hence all the control methods are implemented using the same. Laboratory Virtual Instrumentation Workbench is abbreviated as LabVIEW. The programming done with this software is applied to the prototype system and the results of the controllers are compared and it is found that SMC controller is better suited than PID and fuzzy controllers.***

Index Terms**:** ***Sliding Mode Control, Variable Structure Control, LabVIEW, pH Control, PID Control, Fuzzy Logic Control.***

I. INTRODUCTION

The prototype analyzed is a pH Neutralization system [1]. As pH control is essential in pharmaceutical industries and analytical industries, this prototype is considered. This research work aims to control the pH in a stirred tank reactor. It is nonlinear, which is observed from the titration curves [2]. The pH is maintained at a desired level by altering an acid and a base flow.

The pH sensor used in this prototype model is a combination electrode. It consists of a reference electrode and a measuring electrode. They are built in a single housing. The glass electrode is surrounded by a reference electrode concentrically. The tip of the electrode present at the bottom is the pH sensitive part. This allows temperature compensation to be performed with a single probe.

The flow sensor uses ultrasonic principles to measure flow through the pipes. The flow is computed using the Doppler Effect. When an ultrasonic beam is passed through a flowing fluid, the particles of the fluid reflects the same, the resulting Doppler shift is measured by the flow meter. The transmitted beam gets affected by the moving particles and the fluid velocity is calculated by the frequency shift.

The controllers are designed using LabVIEW software developed by National Instruments, Texas. LabVIEW version 11 is used for monitoring and controlling the system. G programming is used in LabVIEW to write VI programs. The source code was written in the block diagram panel and the corresponding system is obtained in the front panel.

II. THE PROCESS

The physical setup of the process is as follows. It consists of four cylindrical type chemical containers. Each of it has a capacity of 5 litres each. One of the containers contains Hydrochloric Acid (Hcl). Another container consists of the base Sodium Hydroxide (NaOH). The third container is placed at the centre and it contains the sample liquid whose pH has to be made acidic. The glass containers used in this prototype are made up of resist glass anti-chemical corrosion material. The fourth container is called as Continuous stirred tank reactor (CSTR). It is used for mixing the sample solution with proper quantities of acid and base, so that the pH is neutralized. This vessel is also called mixing tank. The stirrer which stirs at proper intervals is made of fibre glass. Apart from the above containers an additional reservoir (cylindrical type) is placed which has the capacity of 10 litres. Fig. 1 shows the block diagram of the process.

A permanent magnet DC Motor with ratings of 12 V DC, 1500 RPM, torque 1kg-cm is use for stirring. Temperature Compensation is provided by a Resistance Temperature Detector (RTD). It has linear input output characteristics. The standard pipings, fittings and manual valves are used which sizes 1/8 to 1/4 inches. It is made up of chemical corrosion resist polyethylene plastic. The transfer of Pneumatic pressure signal is done using nylon tubing. The sensor used to measure pH is glass electrode. The outflow of the acid and base is done with the help of control valves. Hence two control valves are used for this purpose and they are of equal percentage model and two way type. They are of normally closed type. The input signal to the pneumatic valve is pressure signal in the range of (3-15) psi. The current to pressure converter provides this range of signal. In this prototype system two current to pressure converters are used. The whole process is controlled by a PC with the LabVIEW software.

Revised Manuscript Received on August 03, 2019.

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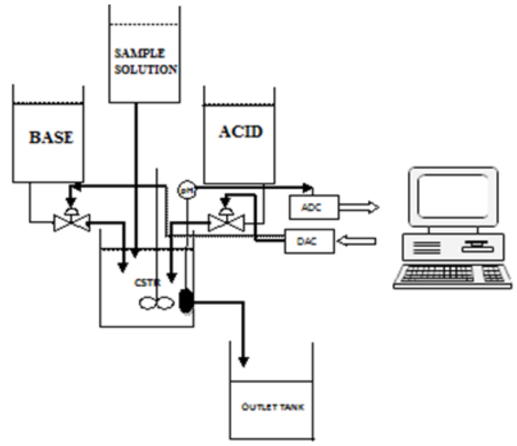

Fig.1. Block Diagram of a pH Neutralization system

As a precautionary measure, the system should be cleaned from any contaminated material before starting the neutralization process. The initial procedure involves calibration of the pH sensor. This is done by using standard or buffer solutions. An online digital computer helps to record the experimental runs. To start the actual process, the tanks are filled with the hydrochloric acid and sodium hydroxide solution. The computer and the process are interfaced by DAQ cards and are verified. The set point is fixed. In this prototype system the required pH of the solution is entered as the setpoint. As four controllers are used, the corresponding controller has to be selected from the PC before starting the neutralization process every time. The codes are written in LabVIEW G programming.

The NI-DAQ input module sends the process variable (pH in the tank) to the computer. The process variable is sent as a current signal varying between 4-20mA. The program helps in generating the error signal which is the difference between the value sent by the input DAQ card and the prefixed set point. The error signal generated is supplied as the input to the controller. The controller then generates a signal which modifies the output to the desired set point. As this output has to be sent to the process, it is first transferred to the output DAQ. The DAQ then send the output to the I/P converted, which thereby opens the corresponding valve of the acid or base tank. The valves of the control valve operates in the range of (3-15) psi. So as the corresponding valves gets opened the acid or base flows into the mixing tank and neutralizes the sample liquid. Again the sensor measures the pH and the whole process continues, until the desired pH setpoint is achieved. The output of this process is extracted into excel sheets and also viewed as graphs in the PC itself.

The prototype as mentioned earlier consists of tanks along with pH electrode and flow sensors. They are also coupled to a control and monitoring unit. The pH sensor is supported with a temperature compensation system as it is a glass electrode. The stirrer stirs at the rate of 1000rpm, and it operates in atmospheric pressure. Three inlet streams are serving as input to the reactor with the help of pumps. The input acid solution is 0.1 M HCl and the input base solution is 0.1 M NaOH. The presence of stirrer makes it behave as a continuous stirred tank reactor. The flow rates of both the acidic and the basic solutions are adjusted to obtain the desired pH value of the sample solution in the tank. All the four controllers are designed using LabVIEW software and are interfaced using NI DAQs.

Fig.2 illustrates the hardware setup of the prototype pH process. The tanks are clearly seen in the figure. Also the equal percentage control valves which control the flow of acid and base are also seen. The tank located at the centre has a amount of sample solution whose pH has to be neutralized. Later Acid or Base solutions are mixed in appropriate quantities thereby helping the controller to neutralize the solution.

Fig.2. Hardware set up of the pH Neutralization plant

III. INTERFACING

DAQ cards (Data acquisition cards) are solely manufactured by the National Instruments are used to interface the pH prototype system and the computer. NI 9203 is the analog input card which is used. It is 16-bit and has 8 channels for input. It is a current input module. Each channel has a terminal to which current signal can be connected. The input signals are buffered, conditioned and sampled by a single 16-bit analog-to-digital convertor. The computer obtains the digital signals that are transmitted. NI 9265 is the analog output current module that is used. It has 4 channels for supplying output. Each channel has a digital-to-analog converter that produces a current signal corresponding to the input digital value. The analog value is then used to control the position of the valves.

The (I/P) converter known as current to pressure converter is used to convert output of NI9265 analog current output card. It converts the output current to an equivalent pressure signal. This is performed using a flapper nozzle system. The flapper opens and closes the nozzle correspondingly thereby generating the corresponding amount of back pressure at the output. The general range is converted from (4-20)mA to (3-15)psi.

The control valve position is regulated by the valve positioners. Valve positioners are also implemented as minute variations in pressure lines.

The control valve has valve positioners that accurately positions the actuator of the valve pressure input received from the current to pressure converter. The valve position determines the extent of opening or closing of the body of the valve, thus controlling the acid or base flow through the pipes.

IV. CONTROLLERS

The pH is controlled in the plant using four different controllers – PID Controller, Fuzzy Logic Controller, Sliding Mode Controller and Dynamic Sliding Mode Controller.

PID controller provides control output by calculating the error between the actual value and the desired value. The error is integrated, differentiated with respect to time and multiplied with a constant gain to obtain the required controller output value. The output is then used to regulate the control valve position.

$$u(t) = K_p e(t) + K_I \int_0^t e(t)dt + K_d \frac{de(t)}{dt} \qquad (1)$$

Where,
Kp is the Proportional gain
Ki is the Integral gain
Kd is the Derivative gain

Fuzzy logic controller is based on a mathematical system that relates analog or linguistic input values in terms of logical variables. Fuzzy logic has the advantage that the solution to the problem is cast in terms that human operators can understand. Fuzzy logic controllers consist of an input stage which senses the inputs, a processing stage that invokes the rules to be applied and an output stage that converts the result into a control output value.

Table 1: Fuzzy rule base used in the Fuzzy Logic Controller.

Input variable	Linguistic Variables				
Error/ Change In Error	Negative High	Negative Medium	Zero	Postive Medium	Positive High
Negative High	Zero	Zero	Normal	High	High
Negative Medium	Zero	Zero	Normal	High	High
Zero	Zero	Zero	Normal	High	High
Postive Medium	Zero	Normal	Normal	High	High
Positive High	Zero	High	High	High	High

The prototype plant is next subjected to a non linear control, known as Sliding mode controller[3],[4]. By application of a discontinuous signal, the dynamics of the pH prototype system gets altered that its trajectories are forced to slide along the sliding surface boundary. The movement of the systems response as it slides along the boundaries is called sliding mode and the locus of the boundaries is called sliding surface[5],[6]. The advantage provided by sliding mode controller is its robustness.

The Sliding Surface is defined in Eq. 2 as

$$S = \delta_s(p_1 - X) \qquad (2)$$

Where δ_s is a positive scalar.

δ_s defines the slope of the sliding surface . X is the desired pH and which is a constant and p_1 is the actual pH of the system.

The control law to drive the system to the sliding surface is given by Eq. 3

$$u = \frac{1}{\alpha_s}.C\left[\alpha_s.a\sqrt{z_1} - W_s \,\mathrm{sgn}(S_s)\right] \qquad (3)$$

A chattering effect [7] is seen at the output of the system. This is a result of the discontinuous control effect during the shift in trajectories [8].

This research is unique in incorporating the whole system control using LabVIEW software. This research presents PID, Fuzzy logic and sliding mode control for a pH neutralization pilot plant. Process modeling approach adopted in this research is based on the Physico-chemical principles and fundamental laws. PID controller gave a satisfactory response but the flow rate of the acid and base were extremely varying, this will decrease the lifetime of the control valves. The Fuzzy Logic Controller exhibited intelligence, which served in quick decision making efficiency of the plant. The sliding mode controller was the least affected by the ambient and environmental conditions which in turn increased the robustness of the system under study and hence the changes in real time were incorporated satisfactorily, but still exhibited chattering output in the flow rate response. This chattering feature of the output can be minimized by incorporating a Dynamic Sliding Mode Controller.

Table 2. shows the comparison of the three controllers on the pH neutralization system. The above results are summarized for their characteristics and response.

Table 2. Comparison of.PID , fuzzy, SMC on pH neutralization system

TYPES OF CONTROLLERS	ERROR	PEAK OVER SHOOT	OSCILATIONS TYPE FOR FLOW RATE	DELAY
PID	0.07	-0.2	HEAVY OSCILLATIONS	28 SEC
FUZZY	-0.19	-0.2`	PERSISTANT OSCILLATIONS	24 SEC
SMC	0.1	-0.2	CONSTANT	30 SEC

To understand the nature of the controllers, the three controllers PID Controller, Fuzzy Logic Controller, SMC Controller were applied to an acidic solution and neutral solution also. The results are as follows.

V. RESULTS

When the pH was fixed as 3, the following were the results that were obtained. Fig. 3 shows the response of the system when PID, Fuzzy SMC and DSMC were applied.

It can be inferred from the graph that all the four responses were similar with very less errors, mainly ranging from 3.25 to 2.75. The interest here becomes the action of the controllers to these responses. This research targets on the efficiency of the controllers to act on the final control element to help the process to achieve these outputs.

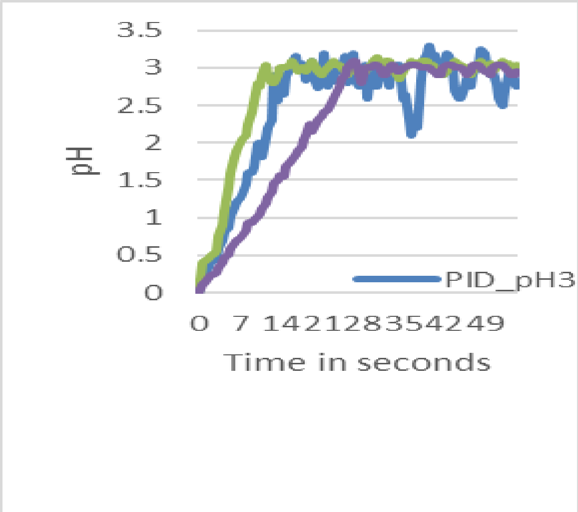

Fig.3. Comparison of the responses for pH= 3 when subjected to the PID, FLC and SMC controllers

Fig 4 indicates the acid and base flow rates of the system when the pH value is set to 3. This graph is obtained when the system is subjected to a PID Controller. It is understood that the flow of acid is more into the solution as it has to maintain the pH at a value of 3.

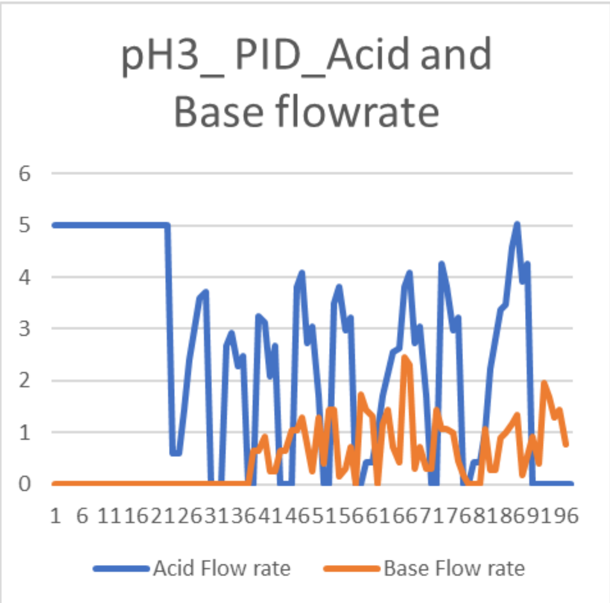

Fig.4. Comparison of the acid and base flow rates when the system is maintained at pH= 3 for a PID controller

Figure 5 shows the controller action of the PID controller when the pH is maintained at 3. The controller exhibits excessive switching action and the pressure on the control valve is heavy in order to achieve the desired pH of the solution.

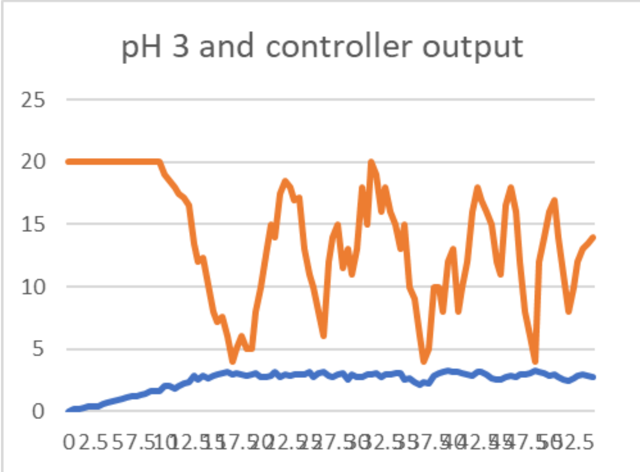

Fig.5. Graphs showing the response of PID controller and pH of the solution when pH is maintained at 3

Figure 6 shows the controller action of the Fuzzy Logic controller [9],[10]when the pH is maintained at 3. Though it is an intelligent controller, in order to give smooth output it exhibits discontinuous switching action, this is a disadvantage to the control valve, to overcome this effect on the final control element SMC and DSMC is applied.

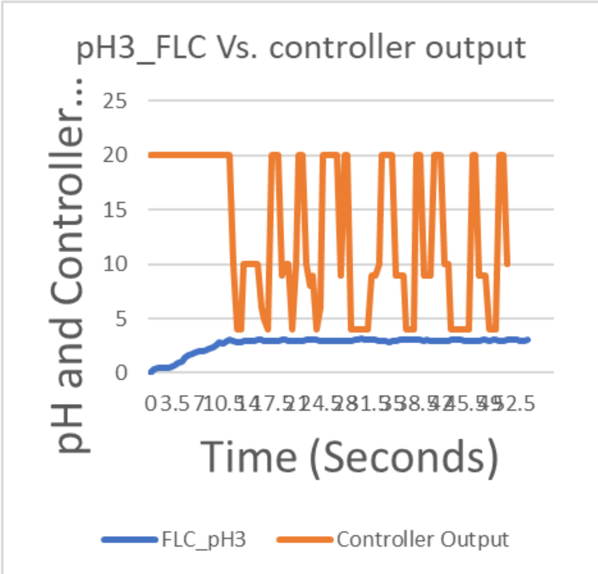

Fig.6. Graphs showing the response of Fuzzy Logic controller and pH of the solution when pH is maintained at 3

Figure 7 shows the controller action of the Sliding Mode controller when the pH is maintained at 3. This robust controller is best suited for non linear process, but it exhibits chattering which is seen in the controller action in the graph. To eliminate this chattering DSMC Controller is applied and results are obtained.

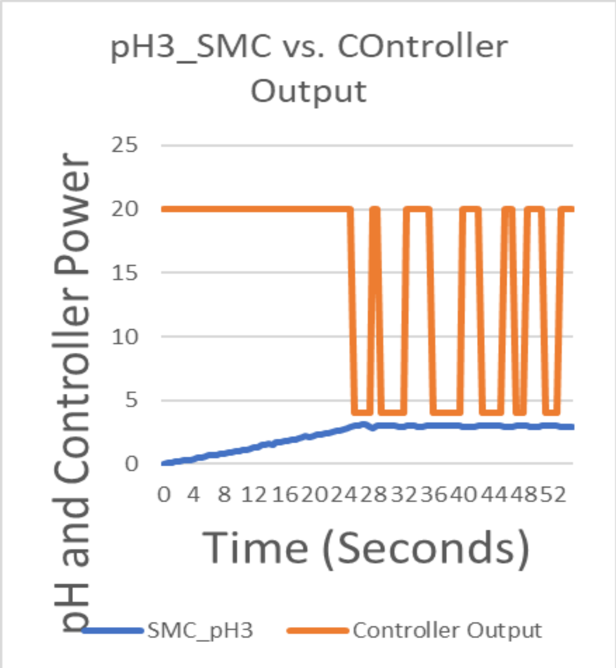

Fig.7. Graphs showing the response of Sliding Mode Controller and pH of the solution when pH is maintained at 3

VI. CONCLUSION

Few researches have been earlier done in this neutralization process. But this paper is unique in incorporating the whole system control using LabVIEW software. This paper presents PID, Fuzzy logic, sliding mode and dynamic sliding mode control for a pH neutralization pilot plant. Process modeling approach adopted in this paper is based on the Physico-chemical principles and fundamental laws. A conventional mathematical modeling process is incorporated. Practical tests are carried out on actual system to estimate manipulating variables which were not known before experiments. The intelligence of the fuzzy logic controller increased the decision making efficiency of the plant. The sliding mode controller increased the robustness of the system under study and the changes in real time were incorporated satisfactorily. The chattering features of the output has been minimized by incorporating a Dynamic mode controller.

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