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Variable Structure Control of pH Neutralization of a Prototype Waste Water Treatment Plant Using LabVIEW

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***Abstract---* This paper aims at developing a control technique using Variable Structure control [VSC] methodology for a pH control plant. The pH control process involves a prototype model in which acidic and alkaline streams are mixed into a Continuous Stirred Tank Reactor [CSTR] in proper proportions so as to control the pH of the plant. The control mechanism involved controls the flow rate of the acid and alkaline solutions. Sliding Mode Control is a type of VSC which is a type of nonlinear control. As the neutralization process is also non linear , VSC serves as a better solution. Also PID control and fuzzy control are incorporated on the same process and the results are compared. The unique feature of this paper is that all the control methods are implemented using LabVIEW SOFTWARE. LabVIEW stands for Laboratory Virtual Instrumentation Workbench. The programming done with this software is applied to the prototype model and the results of PID, fuzzy and VSC are compared and it is found that VSC 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

Wastewater from metal finishing industries contains contaminants such as heavy metals, organic substances, cyanides and suspended solids at levels which are hazardous to the environment and pose potential health risks to the public. The techniques used in the convention treatment of wastewater involve precipitation of heavy metals, flocculation, settling and discharge. The treatment requires adjustment of pH as well as addition of chemicals. pH is monitored and controlled by manipulating an acid and a base stream [1]. Modern treatment plants involve physical and chemical precipitations where maintenance of pH is the key factor for efficient treatment. Most of the processes use a pH sensor as the on-line measuring for control. In the present work, LabVIEW technique is used to operate and control the system automatically by online digital computer. It was found that pH control in a wastewater treatment process is very difficult and the difficulties arise from severe process non-linearity and frequent load changes [2]. The S – shaped titration curve is the primary source of the non-linearity. A possible better solution for better control of pH in a wastewater treatment process is aimed at in this paper using VSC. Some studies have been done in the non linear control area which indicates the robustness of VSC [3]. Sliding Mode Control is a type of Variable Structure Control (VSC). In control theory, sliding mode control, or SMC, is a nonlinear control method that alters the dynamics of a nonlinear system by application of a discontinuous control signal that forces the system to "slide" along a cross-section of the system's normal behavior [4]. The state-feedback control law is not a continuous function of time. Still it can switch from one continuous structure to another continuous structure depending on the present position in the state space. Hence, sliding mode control is a type of variable structure control method [5]. The multiple control structures are designed so that trajectories always move toward an adjacent region with a different control structure, and so the ultimate trajectory will not exist entirely within one control structure. Instead, it will slide along the boundaries of the control structures. The motion of the system as it slides along these boundaries is called a sliding mode. This geometrical locus consisting of the sliding mode boundaries is called the sliding (hyper) surface. In the context of modern control theory, any variable structure system, like a system under SMC, may be viewed as a special case of a hybrid dynamical system as the system both flows through a continuous state space but also moves through different discrete control modes.

Figure 1 shows an example trajectory of a system under sliding mode control. The sliding surface is described by s=0, and the sliding mode along the surface commences after the finite time when system trajectories have reached the surface. In the theoretical description of sliding modes, the system stays confined to the sliding surface and need only be viewed as sliding along the surface. However, real implementations of sliding mode control approximate this theoretical behavior with a high-frequency and generally non-deterministic switching control signal that causes the system to "chatter" in a tight neighborhood of the sliding surface [6]. This chattering behavior is evident in figure below, which chatters along the s=0 surface as the system asymptotically approaches the origin, [7] which is an asymptotically stable equilibrium of the system when confined to the sliding surface. In fact, although the system is nonlinear in general, the idealized (i.e., non-chattering) behavior of the system in Fig. 1 when confined to the s=0 surface is an LTI system with an exponentially stable origin.

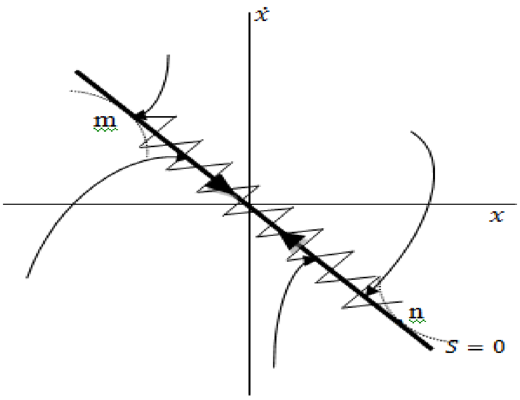

Fig. 1. Sliding surface

Sliding mode control uses practically infinite gain to force the trajectories of a dynamic system to slide along the restricted sliding mode subspace [8]. Trajectories from this reduced-order sliding mode have desirable properties (e.g., the system naturally slides along it until it comes to rest at a desired equilibrium). The main strength of sliding mode control is its robustness. Because the control can be as simple as a switching between two states (e.g., "on"/"off" or "forward"/"reverse"), it need not be precise and will not be sensitive to parameter variations that enter into the control channel. Additionally, because the control law is not a continuous function, the sliding mode can be reached in *finite* time (i.e., better than asymptotic behavior). Under certain common conditions, optimality requires the use of bang–bang control; hence, sliding mode control describes the optimal controller for a broad set of dynamic systems. One application of sliding mode controllers is the control of electric drives operated by switching power converters. Sliding mode control has many applications in robotics. In particular, this control algorithm has been used for tracking control of unmanned surface vessels in simulated rough seas with high degree of success. Sliding mode control must be applied with more care than other forms of nonlinear control that have more moderate control action. In particular, because actuators have delays and other imperfections, the hard sliding-mode-control action can lead to chatter, energy loss, plant damage, and excitation of un-modeled dynamics. Continuous control design methods are not as susceptible to these problems and can be made to mimic sliding-mode controllers. Three controllers are implemented on this prototype using LabVIEW software. A common setpoint is set and the response of the system is recorded and reviewed.

II. THE PROCESS

A. Hardware Details:

The process consists of three chemical containers (cylindrical type) with size 5 litres each. These containers contain an acid (Hcl), a base (NaOH) and the sample liquid whose pH has to be neutralized. They are made of resist glass anti-chemical corrosion material. Another tank is used for mixing the above solutions at proper rate. This vessel is called mixing tank. It also contains a fiber glass stirrer which is used to stir the liquid at proper intervals. The capacity of this tank is also 5 litres. An additional reservoir tank (cylindrical type) is also present which serves as a reservoir whose capacity is 10 litres. The block diagram of the process is shown in Fig 2

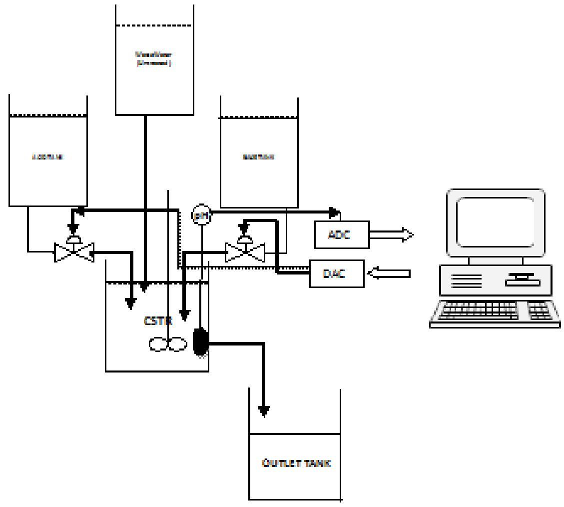

Fig. 2: Block Diagram of the process

A permanent magnet DC Motor with ratings of 12 V DC, 1500 RPM, torque 1kg-cm is use for stirring. An RTD for is provided for temperature compensation. Piping, manual valves and fittings with sizes from 1/8 to ¼ inches were made of polyethylene plastic which resist the chemical corrosion. Nylon tubing is provided for pneumatic pressure transfer. pH measuring sensor uses glass electrode. Two control valves (Equal Percentage type) with 2-way which are of normally closed type are used for acid and base flow respectively. The input signals are 3-15 psi. Both have ½ inch body with ¼ inch trim. The body of acid valve is made of Teflon to prevent corrosion. Two current to pressure converters are used which provides an output ranging from 3 to 15 psi. A PC is used to run the LabVIEW software and control the whole process. Figure 2 shows the block diagram of the process.

B. Experimental Procedure

Before starting, the system is always cleaned from any contaminated material. The pH sensor is calibrated by standard solutions. The experimental runs are achieved by on-line digital computer. The tanks are to be filled with the respective reagents. The interfacing between the plant and the computer are to be verified. The power supplies to the various units are established to be proper and power supply is switched on. The required pH in the tank is to be set and the controller is to be selected from the LabVIEW interface. The process variable (pH in the tank) is sent to the computer through the NI-DAQ input module (in the form of a current signal varying between 4-20mA) and the program generates an error signal depending on the value of the variable. The controller is given the error signal and manipulates it accordingly and generates a control output. The control output is given to the current to pressure converter through the NI-DAQ output module (in the form of a current signal varying between 4-20mA). The current-to pressure converter generates a corresponding pressure depending upon the input current received. The pressure from an current to pressure converter is in the range of (3-15) psi. The pressure is used to regulate the positioner of the acid and base valves. The acid or base valves are thus opened or closed and the pH in the tank is regulated. The outputs are observed in graphical format on the computer and can be exported to Microsoft Excel to obtain values in tabular format.

III. CONTROLLERS

Process control is an engineering discipline that deals with architectures, mechanisms and algorithms for maintaining the output of a specific process within a desired range. Process control is extensively used in industry and enables mass production of consistent products from continuously operated processes such as oil refining, paper manufacturing, chemicals, power plants and many others.

A. PID Controller

A proportional-integral-derivative controller (PID controller) is a control loop feedback mechanism (controller) widely used in industrial control systems. A PID controller calculates an error value as the difference between a measured process variable and a desired setpoint. The controller attempts to minimize the error by adjusting the process through use of a manipulated variable.

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

Where,

K_p is the proportional gain

K_I is the Integral gain

K_d is the Derivative gain

The equation 1 gives the overall controller action for the PID controller. It is the sum of Proportional, Integral and Derivative actions of the error signal.

B. Fuzzy Logic Controller

A fuzzy control system is a control system based on fuzzy logic—a mathematical system that analyses analog input values in terms of logical variables that take on continuous values between 0 and 1, in contrast to classical or digital logic, which operates on discrete values of either 1 or 0. It consists of an input stage, a processing stage, and an output stage. The input stage maps sensor or other inputs, such as switches, thumbwheels, and so on, to the appropriate membership functions and truth values. The processing stage invokes each appropriate rule and generates a result for each, then combines the results of the rules. Finally, the output stage converts the combined result back into a specific control output value. Few research were already performed in pH neutralization system earlier and it gives acceptable results [9],[10]. The membership functions used are triangular. The fuzzy rule base used in the experiment is mentioned below in Table 1.

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

C. Sliding Mode Controller

The Sliding Mode Control (SMC) is a type of Variable Structure Control. It has high insensitivity to disturbances and parameter variations. SMC can be divided into two parts: (i) the design of a stable sliding surface and (ii) the design of a control law to force the system states onto the chosen surface in finite time. The design of the surface should address all constraints and required specifications. A sliding mode controller is a nonlinear control method that alters the dynamics of a nonlinear system by application of a discontinuous control signal that forces the system to "slide" along a cross-section of the system's normal behavior.

Sliding mode control uses practically infinite gain to force the trajectories of a dynamic system to slide along the restricted sliding mode subspace. Trajectories from this reduced-order sliding mode have desirable properties. The main strength of sliding mode control is its robustness. As actuators have delays and other imperfections, the hard sliding-mode-control action can lead to chatter, energy loss, plant damage, and excitation of un-modelled dynamics. The control action in this project is a simple action of switching between two states; it will be less sensitive to parameter variations. The control law is a discontinuous function and so the sliding mode can be reached in finite time. The design of Static Sliding Mode Controller is done by first defining the sliding surface. The Sliding Surface is defined as

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

Where δ_s is a positive scalar.

δ_s defines the slope of the sliding surface. X is the desired pH and p_1 which is a constant and is the actual pH of the system. The control law to drive the system to the sliding surface is given by

$$u = \frac{1}{\alpha_s} C[\alpha_s . \alpha \sqrt{Z_1 - W_s} sgn(s_s)] \quad (3)$$

The system shows a chattering effect at the output. This is due to the discontinuous control effect of the shift in trajectories.

IV. INTERFACING WITH PROCESS PLANT

The experimental apparatus designed for this project is a reactor of 5 litre capacity and pH and flow sensors coupled with a control and monitoring unit. The pH sensor is a glass electrode and has a temperature compensation system provided. The reactor operates at atmospheric pressure and temperature and is stirred at around 1000 rpm. The reactor is fed with three inlet streams provided with pumps. The acid stream is 0.1 M HCl and the base stream is 0.1 M NaOH. The reactor behaves as a continuous stirred tank reactor. Both the acid and the base streams are manipulated to achieve the desired pH level in the tank. The interfacing with the laptop is performed using data acquisition cards provided by National Instruments, Texas. The controllers are designed in the LabVIEW software environment. The data is transmitted to the virtual instrument and the virtual instrument is executed and the amount of acid and/or base to be added is computed and the control valves are manipulated accordingly. Fig. 3 shows the experimental Setup of the process. The figure shows the two tanks which contains Acid and Base solutions. The tank located in the centre contains the waste water whose pH has to be regulated. It also indicates the Continuous Stirred Tank Reactor [CSTR] which is used to regulate the pH by mixing the acid and base solutions.

Fig. 3. Experimental Setup of the process

V. VIRTUAL INSTRUMENTS

The virtual instruments simulating the various control actions are shown. Fig. 4 shows the Front Panel of the whole process. It indicates the controllable features of the system. It allows the change of Ph of the system. The design of the front panel has to be done in such a way that enables the user to use the controls in a familiar method. It consists of knobs, dials and also graphically represented tanks with graduations.

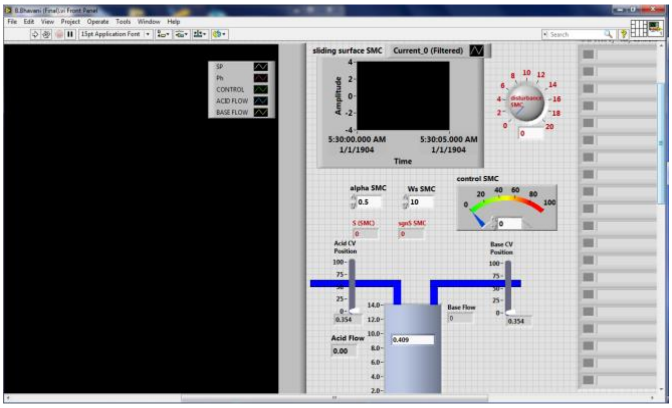

Fig. 4. Front Panel of the process

VI. RESULTS

Before the start of the process, the plant was cleaned to remove contamination and the pH sensor was calibrated using standard solutions. The tanks are filled with the respective reagents – HCl in the acid tank and NaOH in the base tank. The interfacing between the plant and the computer was verified and the desired pH level was selected from the LabVIEW interface. The outputs were then observed in the graphical format. To obtain the exact values at every instant, the graphs were exported to Microsoft Excel and the values were obtained as a variation of time in a tabular format. The desired set point to be maintained in the tank was selected as 13. The following graphs were obtained after the controllers were applied for the process.

A. PID Controller

The set point was set at pH level 13. The pH level attained setpoint after 28 seconds. The overshoot observed was around ±0.2 pH. Fig. 5 indicates the result obtained after applying PID controller. The values of the gain constants used in equation 1 are obtained using tuning techniques. Zeigler nicholos method is used and the following values are obtained.

$K_p = 2.1$

$K_i = 0.042$

$K_d = 0.63$

It can be seen that the response has oscillations. The pH settled at a value of 12.83. Though this is the conventional method, a sudden disturbance introduced in it will make the system take a longer time to settle.

Figure 6 shows the flowrate of acid and base into the tank. From the graph it can be seen that the control valves of the acid and base are pressurized to open and close at very quick intervals of time. This in turn increases the wear and tear of the final control element

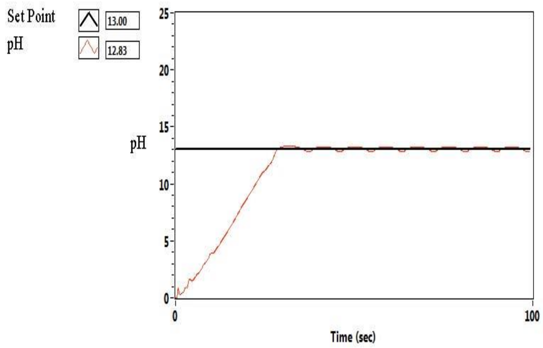

Fig. 5. Graph showing the variation of pH in the tank

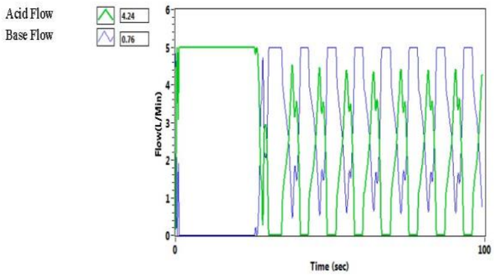

Fig.6. Graph showing the variation of flow of acid and base in the tank application of PID

B. *Fuzzy Logic Controller*

The set point was set at pH level 13. The pH level attained setpoint after 24 seconds. The overshoot observed was around ±0.2 pH. Fig 7 indicates the waveform obtained after application of Fuzzy Logic Controller. The final settled pH value is 13.19. This graph also indicates oscillations. Fig 8 shows the flow of acid and base into the tank. This graph indicates the continuous movement of the valves. This graph has a better performance than PID controller but still excerts pressure on the control valves.

pH being a non linear control is bound to several disturbances, in such cases a more rugged method of control is required. As an attempt to accomplish this, SMC control method is implemented to this system.

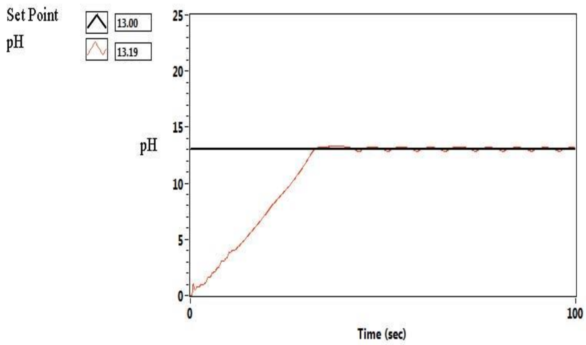

Fig. 7. Graph showing the variation of pH in the tank

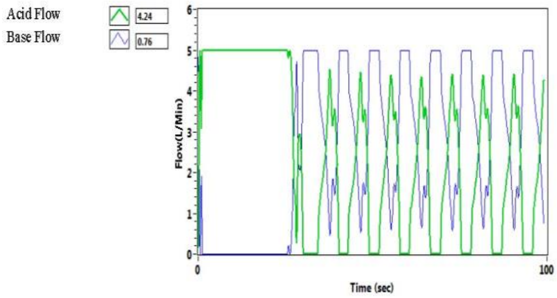

Fig. 8. Graph showing the variation of flow of acid and base in the tank on application of FLC

C. *Sliding Mode Controller*

The set point was set at pH level 13. The pH level attained setpoint after 30 seconds. The overshoot observed was around ±0.2 pH. Fig. 9 indicates the resultant waveform of the system after the application of Sliding Mode Control. This method takes a longer time to settle when compared to the previous methods. But the main advantage is that less oscillation are obtained thereby giving a smooth output. Also Fig 10 shows the flow rate of the acid and base solutions which indicates that the pressure on the final control element is reduced.

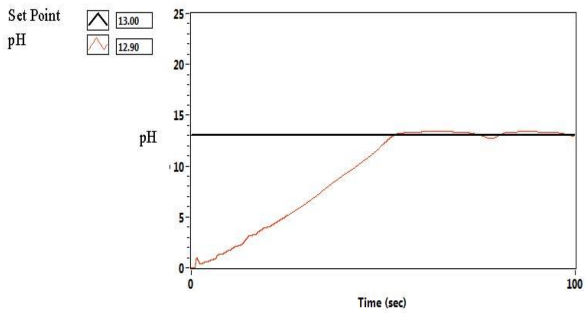

Fig. 9. Graph showing the variation of pH in the tank

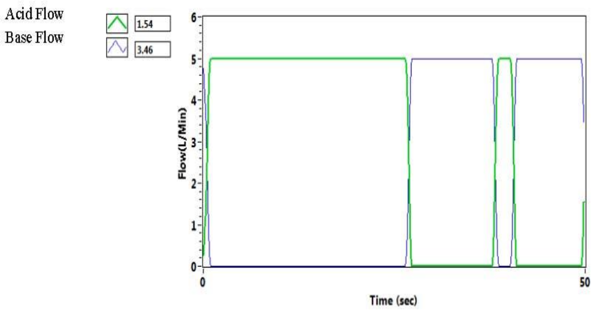

Fig. 10. Graph showing the acid and base flows in the tank

VII.CONCLUSION

Few researches have been earlier done in this neutralization process [11],[12]. But this paper is unique in incorporating the whole system control using LabVIEW software. This paper presents PID, Fuzzy logic and Sliding

Mode 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. Though the PID and FLC controller had less settling time, The oscillations obtained at the response graphs were considerably reduced by the use of SMC. Also the wear and tear of the final control elements were minimized by using SMC

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