pH Controller for Water Treatment Using Fuzzy Logic

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Abstract— **In recent years the industrial application of advanced control techniques for the process industries has become more demanding, mainly due to the increasing complexity of the processes themselves as well as to enhanced requirements in terms of product quality and environmental factors. Therefore the process industries require more reliable, accurate, robust, efficient and flexible control systems for the operation of process plant. In order to fulfill the above requirements there is a continuing need for research on improved forms of control.**

In Industries, pH of a solution plays a major role in the output and efficiency of the system. Deviation in pH can affect health of humans and plants. World Health Organization has issued an order that pH value of metro water should be maintained at 7 which is a neutral value. Nowadays in industries pH value is maintained only using manual methods. This method cannot be determined as error less and accurate. This is one of the most important reasons that an automatic pH controller should be developed and used in industries. During the manual pH control there many possibilities for error to occur which in turn may affect many life forms. This automatic pH control method is fast, error free and accurate.

Keywords— pH, Fuzzy logic,PID controller, acid & base

I. INTRODUCTION

The pH of a solution is the negative common logarithm of the hydrogen ion activity: pH = -log (H^+). In dilute solutions, the hydrogen ion activity is approximately equal to the hydrogen ion concentration. In other words, the pH of water is a measure of the acid–base equilibrium and, in most natural waters, is controlled by the carbon dioxide–bicarbonate–carbonate equilibrium system[8].

pH is one of the most common water quality tests performed. pH indicates the sample's acidity but is actually a measurement of the potential activity of hydrogen ions (H^+) [1,9] in the sample. pH measurements run on a scale from 0 to 14, with 7.0 considered neutral. Solutions with a pH below 7.0 are considered acids. Solutions with a pH above 7.0, up to 14.0 are considered bases. The pH of the water which is used for drinking purpose is always maintained as 7. In industries, there are methods followed to maintain the pH of the drinking water. Some of the traditional methods have disadvantages since this process is a Non- linear process. Using Analytical method, the pH of an aqueous sample is usually measured electrometrically with a glass electrode [6].

Although pH usually has no direct impact on water consumers, it is one of the most important operational water-quality parameters. Careful attention to pH control is necessary at all stages of water treatment to ensure satisfactory water clarification and disinfection. For effective disinfection with chlorine, the pH should preferably be less than 8.

Among all the process that takes place in a water treatment industry pH control and maintenance is one of the most important processes. This is because even if there is any small deviation in the pH value then it will affect the nature of water. Water is consumed by all the living organisms. If there is change in the nature of the water which is consumed by human beings it may affect the health of humans. Manual control which is used in industries nowadays is not accurate and probability of error is very high.

Therefore an intelligent method is implemented to control the pH of the drinking water using Fuzzy Logic [4]. The Technology used here is embedded technology for microcontroller. Visual Basics is used as a base for Fuzzy Logic and PID controller. Visual Basic (VB) is a programming environment from Microsoft in which a programmer uses a graphical user interface (GUI) to choose and modify preselected sections of code written in the BASIC programming language.

A programmer can create an application using the components provided by the Visual Basic program itself. As compared to other languages it may be slower though, yet it is flexible and it can be rightly said that things that are difficult in other languages are comparatively easier in visual basic programming language.

II. PROCESS DESCRIPTION

In the Process tank, the sample (water) for which the pH is to be neutralized is taken. Initially, the set point required for the pH control process is fed to computer by the user. Generally, pH of water ranges from 6.5 to 8.5. The set point for this process is always 7. The pH of the sample is measured using a pH sensor. The output of the pH sensor is analog in nature. Therefore, a PIC microcontroller is used to convert this analog signal into a digital signal.

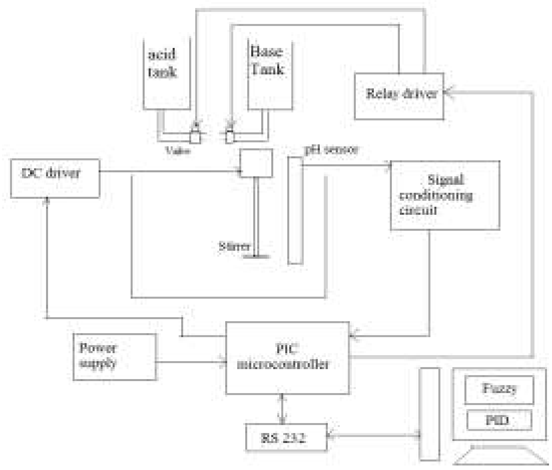


fig. 1. Schematic diagram of the pH Process

This digital signal output is displayed using the computer which acts as a controller for the process. The difference between process variable and the set point is known as error. Depending upon polarity of the error, acids and bases are added. If the error is positive, then basic solution is added to the sample and if the error is negative, then acidic solution is added[9]. The quantity of solutions added depends on magnitude of error. The acid and base solutions are stored in two separate conical flasks. The outflow from conical flasks is controlled by two separate valves. A DC motor is used to operate a stirrer, which is used to mix the solution with the sample thoroughly. When the acid or base is added to the solution, immediately stirrer is turned on to mix the solution. The current pH of the solution is measured by the pH sensor. The output of the pH sensor is an analog, is converted into a digital.

The amount of acid and base to be added is determined by both PID Controller and using Fuzzy Logics. The Fuzzy Logic is an intelligent method; it is used to overcome the disadvantages from PID controller[2]. The Fuzzy Logic does not need mathematical modeling. The pH control process is a Non-linear process. Obtaining mathematical modeling for PID is a difficult process. In Fuzzy logic the rules can be framed according to conditions. The rules are framed for low and high error. The set point of pH for water is always 7. Therefore, the pH below 7 is grouped as Low and pH above 7 are grouped as High. The input from the sensor is converted into a crisp value using fuzzification. After the control action is done the crisp value is again converted into non-fuzzy values and given to the valves.

In PID, the concentration and dissociation constant of the acid and base is considered for the modeling of PID controller. Transfer function for acid and base is obtained. Using this transfer function tuning of PID controller is done by Ziegler-Nichols tuning method. The K_P, K_D and K_I are found using tuning method. The acid and base conditions are operated according to the error.

The time taken for the controller action using both the logics is calculated.

III. SOFTWARE

Visual Basic is a third-generation event-driven programming language and integrated development environment (IDE). Programmers can create both simple and complex GUI applications. Programming in VB is a combination of visually arranging components or controls on a form, specifying attributes and actions for those components, and writing additional lines of code for more functionality. Since VB defines default attributes and actions for the components, a programmer can develop a simple program without writing much code.

The structure of the Basic programming language is very simple, particularly as to the executable code. VB is not only a language but primarily an integrated, interactive development environment. VB provides a comprehensive interactive and context-sensitive online help system. This will provide a very fast response when compared with other software.

IV. PID CONTROLLER

The software being used is Visual Basics for PID controller and Embedded C for Fuzzy Logic[8].

A. Operating conditions for pH

1. Concentration of Buffer Solution

   ACID: HCL: 0.003M
   BASE: NAOH: 0.003M

2. Charge Variants of the Base

   WB1 =0.0M
   WB2 = 0.03M
   WB3 = 5.00 $*10^{-5}$
   WB4 = 5.28 $*10^{-4}$

3. Charge Variants of the Acid

   WA1 = 3.00 $*10^{-3}$
   WA2 = 0.03M
   WA3=-3.05 $*10^{-3}$
   WA4 = -4.32 $*10^{-4}$

4. Dissociation Constant

   HCL = 1 $* 10^{3}$
   NAOH = 0.2

5. Area of the Process Tank

Diameter = 14cm
Height = 12cm
Area = 2 x 3.14 x7 x12 = 527.52 m^2

B. PID Tuning

A unit step response on pH model can be modeled[6,9] as FOPDT system whose transfer function is

$$g_p(s) = \frac{K_p}{\tau_p(s)+1} e^{-DS}$$

A PID controller equation (parallel form) $g_c(s)$ can be expanded about zero in Maclurian series as

$$g_c(s) = \frac{1}{s}\left[F(0) + F'(0)s + \frac{F''(0)}{2!}s^2 + \cdots \right]$$

Comparing coefficient of an ideal PID controller equation with that of the above equation

$$K_c = F'(0); \qquad \tau_i = \frac{F'(0)}{F(0)}; \qquad \tau_D = \frac{F''(0)}{2F'(0)}$$

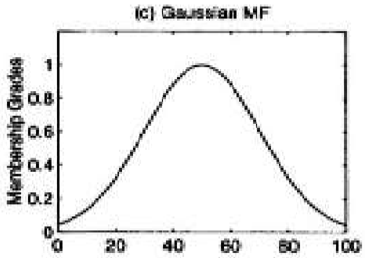
V. FUZZY LOGIC

When a solution is taken for which the pH should be controlled, the pH varies due to different concentration solutions added to it. pH measurement and control is a Non-linear process. It is very difficult to develop the mathematical modeling for this process. Therefore an Intelligent Method or logic is used to control the pH of the solution.

Fuzzy Logic is used to control the pH process (Non-linear process). The term "fuzzy" [7,11]refers to the fact that the logic involved can deal with concepts that cannot be expressed as the "true" or "false" but rather as "partially true".

In pH process, the pH sensor is immersed into the solution or liquid whose pH should be measured. The output of the pH sensor is in terms of Voltage (0-100 mV). This voltage is calibrated in terms of pH. The voltage from the pH sensor is given as input to the fuzzy controller. A suitable membership function is selected and rules are formed in it. Membership functions are classified into varies types according to the process.

Gaussian Membership function is used in pH controller process[11]. The Gaussian membership function is used because the previous error is compared with the present error. The symmetric Gaussian function depends on two



parameters σ and c as given by,

$$F(x;\sigma,c) = e^{-((x-c)^2/2\sigma^2)}$$

Fig.2. Gaussian membership function

The output of the pH sensor is a voltage ranging from 0-100 mV. The 0 mV indicates strong base solution (pH=14) and 100 mV indicates strong acid solution (pH=1). The pH value is calibrated according to the voltage output. The rules base is classified as:

ph Low (100-56 mV)

pH Medium (56-54 mV)

pH High (54-1 mV)

If the output from the pH sensor is pH Low, then the base valve is opened. If the output from the pH sensor is pH High, then the acid valve is opened. If the output from the pH sensor is pH Medium, then both the valves are closed since pH is equal to the set point. Thus the fuzzy values are converted into the crisp value[4,12] and given to the control element.

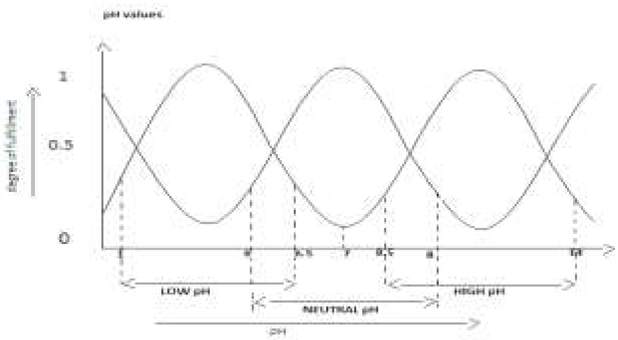
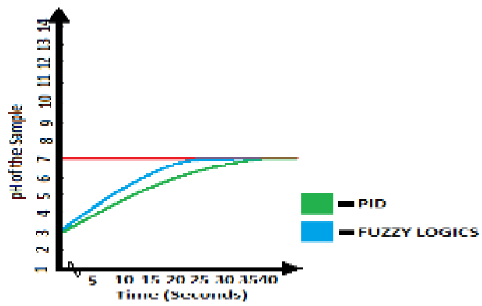


Fig. 3. Membership function definition for change of pH



VI. OPEN LOOP CHARACTERISTICS

Using Ziegler Nichols open loop tuning parameters the value of Kp, Ti, Td can be determined

Fig.4. open loop characteristics of pH loop

For Base:	For Acid:
Slope N = 0.025	Slope N =- 0.027
Dead time = 10s	Dead time = 10s
Kp = 1.2 / dead time * N = 4.48	Kp = 1.2 /dead time * N = -4.31
Ti = 2.0 * dead time = 20	Ti = 2.0*dead time= 20
Td = 0.5*dead time = 5	Td = 0.5*dead time = 5

Using the above parameters the equations for Acid and Base are found[9]. Base process model transfer function has been found from open loop step experiments as:

$$\frac{4.48 * e^{-0.0105s}}{0.364s+1}$$

and the acid-process model transfer function has been calculated as: $\frac{-4.313 * e^{-0.0514s}}{5.404s+1}$

The flow rate of the water cannot be considered since the flow of water is in terms of droplets. The process of tuning will vary from the acid and base that we select.

VII. RESULTS AND DISCUSSION

When the current pH is 3 and set point is 7 the response of the PID and fuzzy systems are shown below. The desired pH value for the taken sample is given as the set pH value. The current pH value of the solution in the process tank is shown in the current pH value. The output voltage of the pH sensor is shown in the left corner box. The current pH values are obtained instantaneously for all iterations. The total number of iterations is shown in the top of the output. The time that is required to attain the set value is shown in the left of the output. This time is calculated in seconds and this counter starts running when the process begins.

The time taken to complete the process using PID controller is higher than the time taken to complete the process using the Fuzzy control method. When the current pH is 3 and set point is 7 the PID controller takes 34 seconds to complete the process but the fuzzy controller takes only 21 seconds to control the process. So the time taken to attain the steady state value is small for fuzzy when compare with the PID controller

Table 1. output of PID controller

Current pH	Set Point	Time taken to reach set point
3	7	34 seconds

Fig.5. PID output

Table 2. Output of Fuzzy controller

Current pH	Set Point	Time taken to reach set point
3	7	21 seconds

Fig.6.Fuzzy output

VIII. CONCLUSION

Automated pH controller is successful designed using fuzzy logic. One of the main purposes of this is to develop a form of process model that can be applied to real plant involving industrial actuators and industrial measuring devices and instrumentation.

pH value of water which is controlled is shown in both numerical and graphical form in pc. Graphical output of PID controller and fuzzy logic is displayed to compare their performance. The relays and drivers are successfully interfaced with microcontroller. RS232 serial communication port is used to connect the pc with microcontroller

Advantages of using Fuzzy logics over PID controller are disturbance rejection and robustness, no mathematical modeling required, any concentration of acid and base can be added, settling time is lesser when fuzzy logic is used.

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