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Control of pH Neutralization Process using Fuzzy Logic: A Review

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Abstract- *The demand for application of advanced control strategies for process industries is increasing rapidly due to complex nature of industrial processes. The demand also increases to achieve improvement of the product quality and environmental factors. One such example of complex process is the pH neutralization process. The pH neutralization process is considered as highly requisite in many applications such as pharmaceuticals, chemical industries, wastewater treatment, biotechnology and many more. The process in which opposing solution is added to acid or base in order to achieve a solution with pH value of 7 is known as pH control. The controller should be designed in such a way that neutral output of the system is obtained. The pH neutralization process is highly nonlinear and has time varying characteristics where gain changes by several order. These characteristics are clearly seen in the titration curve which indicates the fundamental nonlinearity for the pH neutralization process.Due to this reason no exact mathematical model for pH neutralization process can be developed. Hence controlling the value of pH is considered to be difficult. The control of pH is very difficult and depends on nonlinear control techniques .Fuzzy logic and neural network based controllers are example of nonlinear control strategies which provide satisfactory control performance as compared to the classical control schemes. The conventional PI controllers are not able to control the nonlinear system satisfactorily. Fuzzy logic control provides better choice to the classical PI controller. This paper reviews the development of fuzzy logic tools for pH neutralization process.*

Key Words: *Fuzzy Logic, pH Neutralization, Wastewater Treatment, Conventional PI Controller*

1. INTRODUCTION

The Control of pH is trivial in wastewater treatment, biotechnology, pharmaceuticals and chemical industries. Before discharging wastewater in environment its value of pH must be maintained between 6 to 8 to protect human and aquatic life. The pH neutralization plays vital role in pharmaceutical to ensure the quality of the product. Controlling the value of pH is problematic due to its nonlinear characteristics and time varying nature. These process exhibit severe static nonlinear behaviors as the process gain vary several orders of magnitude over a modest range of pH values [1].Usually conventional control techniques are developed on the basis of linear theory when such techniques are applied to chemical systems having kinetic reactions and thermodynamic relationships they provide inadequate system performance and unsuccessful in capturing entire operating range. The pH neutralization process mainly consists of pH measurement of an acid base chemical reaction where hydrogen ions and hydroxide ions are neutralized with each other to form water, while the other ions involved remain unchanged [2].

The titration curve clearly indicates the nonlinearly associated with pH neutralization process [3]. For small change in the input the value of pH changes rapidly. There is considerable variation in the slope of the titration curve and the curve is not symmetrical about pH=7.

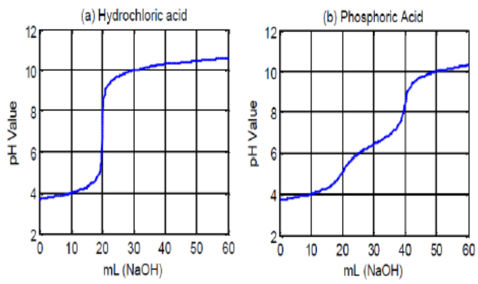

Fig -1:Titration curve for acid base process reaction

2. THE pH CONTROL METHODS

The pH control methods are generally divided into three main categories. The first category is open loop type of control in which the control value opening is kept at certain position for specific time duration. The second category based on feedback control principle in which there is direct relationship between the control valve opening and pH value in the process. The third control method that is widely used for pH control is feedforward control, in which the controller will compensate for any measured disturbance before it affects the process [2].

The nonlinear change in the value of pH with the reagent flow makes close control of pH difficult .A change in the set point can lead to change in process gain and optimum controller gain several fold and eventually lead to unstable oscillations. Also the system used to control pH should be able to cope with severe load changes which results from changes in concentration and change in flow .Process gain may get affected by large load change and it also alter the time constants of the system which makes the design of control system difficult. For such systems, controlling with conventional controller is very difficult. On the other hand a fuzzy controller is very successful in handling such system with nonlinearities and various complexities.

3. THE pH NEUTRALIZATION PROCESS

The pH control is mandatory in many industrial processes. The basic strategy is to neutralize the pH of the liquid i.e. attain a pH value as close as to 7.Continuously Stirred Tank Reactor (CSTR) is used for a pH neutralization process. Depending on the pH value of the solution sensed by pH sensor, acid or base is added to the solution to obtain neutralized solution.

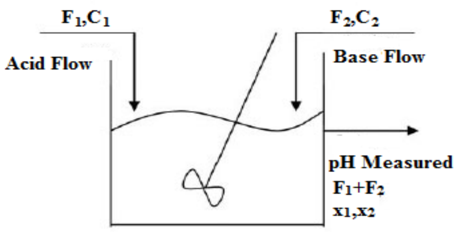

Fig-2. A continuously stirred tank reactor for pH titration control

The mixing dynamics are

$$V\frac{dx1}{dt} = F_1C_1 - (F_1+F_2)\,x_1$$

$$V\frac{dx2}{dt} = F_2C_2 - (F_1+F_2)\,x_2$$

Where C_1, C_2 is concentration of acid and Base stream (mole liter^{-1}) respectively, x_1, x_2 is concentration of non reacting acid and base solution in tank, F_1, F_2 is the flow rate of acid and base stream (liters^{-1}) ,F_1+F_2 is flow rate of effluent stream, V is volume of the mixture in the CSTR [5].

The characteristics equation for the pH curve for strong acid strong base reaction is given by

$$pH = -\log\left(\sqrt{0.25C^2+10^{-14}} + 0.5C\right)$$

where C is the excess concentration which measure the concentration of hydrogen ions in excess to that found in water [11].

4. FUZZY LOGIC – AN INTRODUCTION

Most of the real world processes which are nonlinear in nature are difficult to control using classical controller due to varying operating point. Fuzzy logic facilitates the incorporation of human intelligence in the field of automation. The nonlinear systems or systems whose mathematical models are not known can be controlled easily by means of fuzzy algorithms, based on intuitions and experience of operators. Fuzzy logic introduced by Zadeh, is a tool to attain the tolerance for imprecision and uncertainty to achieve tractability. Fuzzy logic is a method for implementing decision making functions with the help of if then rules [7].

Japan has found success in commercial and industrial problems by the use of fuzzy logic in controller design. An air conditioner from Tokyo's Mitsubishi Heavy industries Ltd. achieved a power reduction of 20 percent by the use of fuzzy logic algorithms alone. More than 70% of all washing machine in Japan are fuzzy logic controlled [8].

4.1BASIC STRUCTURE OF FUZZY LOGIC CONTROLLER

Fuzzy logic controller mainly consists of four principle components i.e.

- Fuzzification Interface
- Knowledge base
- Decision making logic
- Defuzzification interface

A. Fuzzification Interface
The fuzzification interface measures the values of variables. Then it performs a scale mapping that transfers the range of value of input variables into corresponding universe of discourse. Finally it converts the input data into suitable linguistic values which may be viewed as labels of fuzzy sets.

B.Knowledge Base
The knowledge base consists of knowledge of application domain and attendant control goals. It consists of a "data base" and "linguistic" (fuzzy) control rule base. The data base provides necessary definitions which define the linguistic control rules and fuzzy data manipulation in an FLC. The rule base consists of control goals and control policy of the domain expects by the means of a set of linguistic control rules.

C.Decision making Logic
The decision making logic is the main component of an FLC. It has the ability to simulating the human decision making which is based on of fuzzy concept and capability of inferring fuzzy control action employing fuzzy implication and the rules of inference in fuzzy logic.

D.Defuzzification interface
The defuzzification interface does scale mapping i.e. converts the range of values of output variables into corresponding universe of discourse. Defuzzification yields non fuzzy control action from an inferred fuzzy control action [9]

5. BENEFITS OF FUZZY LOGIC

The main advantages of fuzzy logic control over conventional control are as follows:

- Fuzzy logic has the ability of controlling nonlinear processes. This control is achieved by formalizing the expertise of an operator who has prolonged experience in handling and tuning the process or a designer who has vast engineering knowledge in the specific area of process control engineering.
- For processes which do not have precise mathematical method are difficult to control by classical control method. Fuzzy logic provides simple solution for model development of such processes.
- Fuzzy logic is capable of producing accurate and reliable solution from imprecise or vague information. Hence fuzzy logic is able to resemble human decision making process.
- Fuzzy logic uses linguistic approach which is easy to interpret than complex mathematical form of description. Hence fuzzy logic system is relatively easy and implementation is straight forward [10].

6. FUZZY LOGIC IN pH NEUTRALIZATION PROCESS

Ranganath Muthu and Elamin EI kanzi [11] from University of Bahrain designed fuzzy logic controller (FLC) to carry out simulation of pH neutralization process. It was concluded from the simulation results that the FLC is able to control the pH neutralization process better. Simulation was carried out in MATLAB environment using Simulink and Fuzzy logic tool box.

Maulik Parekh et.al [7] from Texas Tech University preformed laboratory experiments to demonstrate that the Fuzzy logic controller works well over a wide operational range for pH Neutralization process. The pH neutralization process is well known for its severe process nonlinearity which is seen in the titration curve and also shows process gain change of up to 10,000 to l over a very small region. New technique of in line control of pH neutralization based on fuzzy logic was been described.

S. Joe Qin et. al [12] proposed a multi region fuzzy logic controller for nonlinear process control. PI type of fuzzy controller which uses only control error and change in control error is not capable of detecting the process nonlinearity and makes a control move accordingly. Due to this reason the pH neutralization process is divided into fuzzy regions such as high gain, low gain, large time constant and small time constant Depending on the regional information fuzzy controller were designed, where auxiliary process variable help to detect the process operating region. It was concluded that the resulting multi region fuzzy logic controller gives satisfactory performance in all regions.

Nio Tiong Ghee et.al [5] conducted research and experiments to build a fuzzy controlled PID controller to control the pH neutralization process. SIMULINK software in MATLAB was used for process modeling and control. Fuzzy PI controller was designed and then tested on servo and regulator problem. It was observed that the result of servo test was a near prefect response with no overshoot or oscillatory response. The response time had practically no lag time and was very quick. Regulator test had response that changed in tandem with the disturbances but was limited to a narrow range of < 0.01 PH units

Sebastian George et.al [4] presented hybrid fuzzy logic P+I control for pH Neutralization in the juice classifier. Fuzzy controller was successful in handling nonlinearities and various complexities without development of mathematical model. On the other hand all the advantages of conventional P + I controller was retained. It was found that the hybrid controller was more efficient in tracking the set points and was more stable when compared with classical P+I controller.

Shahin Salehi et.al [13] addressed on adaptive control scheme based on fuzzy logic for pH neutralization process. No composition measurement was required for the implementation of proposed scheme. Stability of the closed loop system was established and it was shown that solution of the closed loop system is uniformly ultimately bounded and under a certain condition, asymptotically stability was achieved. Simulation results indicated that proposed controller had good performance in set point tracking and load rejection and was much better than that of a tuned PI controller.

Parikshit Kishor Singh et.al [14] presented fuzzy logic based control scheme for pH neutralization process .This control scheme uses genetic algorithm to optimize fuzzy inference system. Again adaptive neuro fuzzy inference system for pH neutralization process is developed. Performance of both control schemes were compared for servo and regulatory operations. It was concluded that the adaptive neuro fuzzy inference system based control uses fewer rules as compared to optimized fuzzy logic based control.

7.FUZZY LOGIC AND PROBABILITY THEORY

In many real world applications, we use measurement based, numerical perception based or linguistic information. The probability theory is based on perception and has only two outcomes (true and false). Similarly fuzzy theory is based on linguistic information and is extended to handle the concept of partial truth and partial false [15].

Fuzzy set is not a one sided object and that the research of the relationships between fuzzy sets and probability is beneficial in the sense that they focus on development of new practice over old concepts. The novel concept of probabilistic fuzzy system (PFS) uses a new concept of probabilistic fuzzy rule to include randomness in fuzzy systems. Therefore, they are efficient for modeling real world systems with uncertainties. It is proven that the fuzzy logic and probability theory are both powerful tools for handling uncertainty of real world processes. They are considered as complementary rather than competitive. Fuzzy logic represents non statistical (deterministic) uncertainty while the probability theory represents statistical (random) uncertainty. When both of those uncertainties exist at the same time in real world applications, probabilistic fuzzy logic can be used to handle such cases. A probabilistic fuzzy system is a generalized fuzzy system which uses the probabilistic fuzzy logic in presenting a new concept of probabilistic fuzzy rule [16].

Basically the modeling approaches are divided into two categories i.e. deterministic model and probabilistic model. Former one presents a deterministic mapping between inputs and outputs while the later one presents modeling of stochastic systems and can be characterized by the statistical properties of some random processes in the system. Fuzzy modeling techniques are widely used for modeling complex and nonlinear deterministic system. Use of probabilistic fuzzy modeling approach is unavoidable because many control applications exhibit randomness in their behavior. While designing control system uncertainties have to be considered. The probabilistic fuzzy logic technique takes care of such uncertainties [17].

8. CONCLUSION

This paper reviews the use of fuzzy logic in pH Neutralization process. The pH neutralization process is considered as highly nonlinear and time varying process, hence cannot be controlled efficiently using conventional controllers. Fuzzy logic controller is capable of providing optimized solution for such processes. Fuzzy logic controller can be used long with conventional controllers to obtain better performance for pH neutralization. Such controllers are called as hybrid controllers as they take advantages of both the controllers. Genetic algorithm and neural network technology can be used along with fuzzy logic to obtain most feasible and versatile system. Probabilistic fuzzy system which is the combination of probability and fuzzy logic can be used for modeling and control of real world systems which are random in nature.

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