International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 -0056
Volume: 02 Issue: 03 | June-2015 www.irjet.net p-ISSN: 2395-0072

Controllers used in pH Neutralization Process: A Review

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Abstract - ***pH process control has been widely used in chemical, food industry, wastewater treatment and environmental protection. Improving the pH neutralization process accuracy is helpful to the effective control, and has a profound effect in improving the quality and output of the products, as well as the safety of production equipment and the environmental protection. The identification and control of the pH neutralization process has been one of the most difficult problems in relative fields. Due to the influence of serious non-linear, time delay, and strong interference in pH neutralization process contains complex nonlinearity at neutralization point. Therefore, this paper focused on different control strategies like controller using PID, Fuzzy based model, neural network based model and hybrid models for pH neutralization process.***

Key Words: pH neutralization process, PID and PI controller, Fuzzy logic controller, artificial neural network controller.

1. INTRODUCTION

Control of pH neutralization processes is a challenging problem and has received considerable attention because of its importance in the chemical process industry. These processes are difficult to control because of their inherent nonlinearity, high sensitivity at or near the neutralization point, and time-varying gains when uncertainties in flows and concentrations of neutralization agents are present. Thus pH neutralization process is considered as a benchmark for testing nonlinear controllers. Thus the research of the identification and control in pH neutralization process is very important. Extensive researches in the identification of pH neutralization process have been done by many relative experts for many years.

$$pH= -\log [10\ H^{+}] \qquad \text{---------(1)}$$

Most of the factories waste is mainly alkaline; this certainly harms the environment by poisoning life onshore or offshore, including humans either through contaminated food and Water or through breathing. So it is a must to neutralize the industry waste by neutralizing the pH. This is quantitatively done by bringing the pH to around the neutral value of seven. In industry, the pH could vary between any value between 2 and 10. The neutralization process basically follows the following reaction:

$$(HCL+NAOH=NACL+H_2O)$$

This reaction results in salt and water which do not present any harm to nature. The pH neutralisation system basically consists of two liquid streams (acid and base); one feeding the acidic substance and the other feeds the base liquid. The added liquid is controlled by a proportional control valve by the controller whereas the base liquid is manually operated. To make the mixture homogeneous, a variable speed mixer or stirrer is used. The pH is picked up with the aid of a probe placed into the mixing vessel close to the outlet.

1.1 pH Neutralization Process

The process can be considered as a continuous stirred tank reactor (CSTR) to neutralize a strong acid with a strong base manipulated by a control valve. The process consists of an influent stream (HCl), reagent stream (NaOH) to regulate the pH of the effluent stream. The components of a general control system as well as the specific features and problems of pH-control are clarified, with an example consisting of a simple but excessively instrumented neutralisation process (Fig. 1), where strong base (control flow) is used for neutralising acidic liquid (inflow) in order to achieve neutral outflow. The inflow F_I, its contents and the outflow F_3 change in an unpredictable manner and these variations are the main disturbances in the neutralization process. As a result of the changing flows the reactor volume V also changes (it can be assumed that there are safeguards so that the vessel never overflows or becomes empty). The only freely manipulated variable (control variable) is the valve opening x.

Table -1: The main disturbances are:

Available measurements	Main disturbances
Inflow ($F_{I,m}$) Volume (V_m) -Inflow pH-value ($pH_{1,m}$) Outflow pH-value ($pH_{3,m}$) Control flow ($F_{2,m}$)	Inflow (flow changes) (F_I) -Inflow properties (changes in acidity,**C**) -Outflow(flow changes) (F_3) Other dependent variables are: -Volume of the neutralization vessel (V) - Control flow (F_2)

The control reagent (strong base) concentration can be assumed constant as well as the pressure inside the control flow pipe. The physical limits of the variables are never encountered (inflow is always acidic, there is always liquid in the vessel and it never overflows, etc.).

The block diagram structure of the neutralization process can be built up from simple unit blocks. For instance, the inflow acidity has an obvious effect on the pH value inside the reactor. With crude simplification, it can be said that the pH-value of the inflow (pH_1) affects the reactor pH-value (pH_R), which, in turn, has an effect on the outflow pH-value (pH_3)

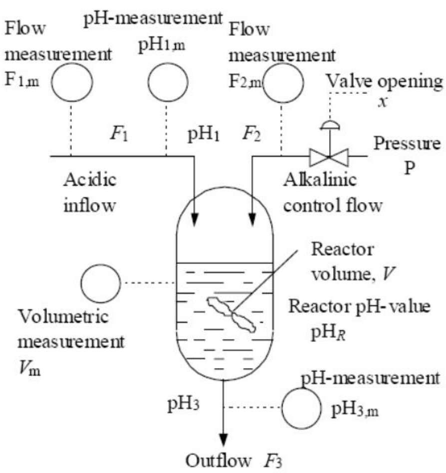

Fig -1. Schematic of a pH Neutralization Process

1.2 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 set point. The controller attempts to minimize the error by adjusting the process through use of a manipulated variable [10]. The PID controller algorithm involves three separate constant parameters,and is accordingly sometimes called three-term control: the proportional, the integral and derivative values, denoted P, I and D. Simply put, these values can be interpreted in terms of time:P depends on the present error, I on the accumulation of past errors, and D is a prediction of future errors, based on current rate of change.

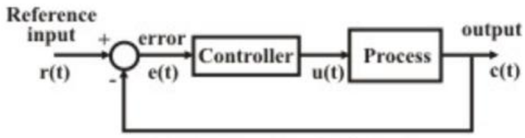

Fig- 2. A closed loop PID Controller

The controller may have different structures. Different design methodologies are there for designing the controller in order to achieve desired performance level. But the most popular among them is Proportional-Integral-derivative (PID) type controller. Equation 1 describes the most basic form of continuous PID algorithm in the time domain. As shown in the equation, the PID algorithm is actually a simple single equation with three control terms; proportional gain, (K_P), integral gain, (K_I) and derivative gain, (K_D). The variable $mv(t)$ represents the controller output while the variable $e(t)$ is the error, which is the difference between the system output (the measured pH in this case) and the set point.

$$Mv(t)=K_P e(t) + K_I \int_0^t e(t)dt + K_D \frac{de(t)}{dt} \quad \text{........ } 1$$

Tuning is adjustment of control parameters to the optimum values for the desired control response. Stability is a basic requirement. However, different systems have different behavior, different applications have different requirements, and requirements may conflict with one another. The most widely used simple feedback control strategy applied to pH control involves the PID algorithm.

PID tuning is a difficult problem, even though there are only three parameters and in principle is simple to describe, because it must satisfy complex criteria within the limitations of PID control. Jari M. Bolinga [2] has developed and evaluated a **multi-model adaptive PID controller** in a simulation study for a nonlinear pH neutralization process. The performance and robustness characteristics of the multi-model controller are compared to those for conventional PID controllers and an alternative "multi-model interpolation" controller. The simulations indicated that the multi-model controller was quite effective over wide ranges of unmeasured disturbances and process changes. Andrey Popov, Adel Farag and Herbert Werner[3] has proposed

Multi-objective Optimization Genetic Algorithm (MOGA) approach for tuning of a PID controller in pH neutralization process. By using a using a combination of both methods to find a fixed-gain, discrete-time PID controller for a chemical neutralization plant which gives superior efficiency.

Qinghui Wu, Zongze Cui [4] has proposed nonlinear compensator based PI controller for neutralization plant which gives good dynamic and steady-state performance and withstand large disturbances. PID controllers, when used alone, can give poor performance when the PID loop gains must be reduced so that the control system does not overshoot, oscillate or hunt about the control set point value. They also have difficulties in the presence of non linearities, may trade-off regulation versus response time, do not react to changing process behavior, and have lag in responding to large disturbances.

Ahmmed Saadi IBREHEM [5] presented modified model for the neutralization process of Stirred Tank Reactors (CSTR) reactor. Also investigates the effect of important reactor parameters such as ionic concentrations and acid and base flowrates on the dynamic behavior .N. R. Lakshmi Narayanan, P. R. Krishnaswamy and G. P. Rangaiah [6] has formulated the adaptive internal model control (AIMC) strategy by combining the concepts of adaptation as in robust non-linear control law (RNCL), non-linear internal model control (NIMC) structure and strong acid equivalent (SAE). The resulting control system provides significant improvement in disturbance rejection compared to the performances of RNCL and SAE-based NIMC when used alone in pH neutralization. pH controllers using robust nonlinear control optimize the desired closed loop speed of response while satisfying robust stability or disturbance suppression constraints.[7]

Model predictive control (MPC) is one of the most successful controllers in process industries algorithms that control the future behavior of a plant through the use of an explicit process model [8]. Therefore, the core of the MPC algorithm is a dynamic model. MPC based on linear models are acceptable when the process operates at a single set point and the primary use of the controller is the rejection of disturbances but many chemical processes, however, do not operate at a single set point, and they are often required to operate at different set points depending on the grade of the product to be produced. Because these processes make transitions over the nonlinearity of the system, linear MPC often results in poor control performance. The MPC based on the Wiener–Laguerre model outperforms the MPC based on the Wiener model, particularly when the system is operating away from the nominal operating conditions MPC based on Wiener model as well as Laguerre model. Nonlinear model predictive control (NMPC) based on Wiener–Laguerre shows better performance compared to the MPC based on Wiener model but is slightly better than MPC based on Laguerre model. A Generalized predictive control (GPC) algorithm was implemented experimentally in a pH neutralization process [9]. A multi-model predictive control strategy is applied to handle the highly nonlinear pH process. A comparison study of the disturbance-rejection performance between the proposed MM-MPC algorithm and fuzzy gain-scheduling shows the superiority of the multi-model predictive control in terms of both settling time and robustness [10].

An autoregressive integral moving average with external input (ARIMAX) model was used as a system model for the GPC algorithm which is tuned by genetic algorithm. Ahmmed Saadi IBREHEM [11] has developed a modified dynamic structure model. This model takes into account the presence of acid and bases in the reaction with ions which depend on chemical reactions of acid and bases concentrations feeds also the concentrations effect of acid and bases on the system were included.

T.Hong, A.J.Morris, M.N.Karim, J.Zhang, and W.Luo [12][13] has developed an on-line modelling method for nonlinear and time-varying processes based on the application of the structure-time-varying Nonlinear autoregressive with exogenous inputs model (NARX) in a pH waste water neutralisation process. By using this much better control behaviour could be achieved if the effective time delay of the system is smaller.

Model predictive control (MPC) has gained wide popularity as a straightforward method to design suboptimal controllers [14]. In model predictive control, the control signal is determined by solving an optimization problem on-line at each sampling instant. The approach has been applied industrially in particular to multivariable systems subject to constraints. Model predictive control is also a promising technique for nonlinear control. A major obstacle for applying MPC to control nonlinear systems is, however, the heavy computational burden associated with the on-line optimization required to compute the control signal.

2. FUZZY LOGIC BASED CONTROLLERS

The performance of fuzzy control logic is dependent on the choice of the membership function of input and output sets. All the process variables are controlled automatically, with the set point being the only exception, which is set manually. Fuzzy logic controller mainly consists of three sections or steps (figure 3):

(i) Fuzzification: It is the process of converting the process variables (system inputs) into grades of membership
(ii) Fuzzy interference: It is the process of mapping the input space on to output space using membership functions, logic operations and if-then rule statements
(iii) Defuzzification: It is the process of providing quantifiable values

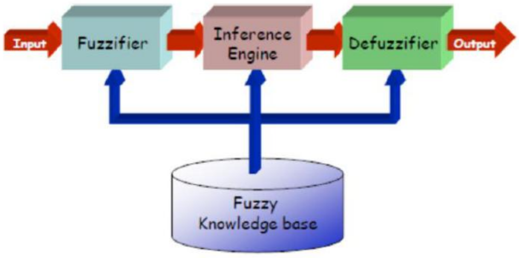

Fig -3.The architecture of Fuzzy Interference System

The automatic control of the other variables is done on the basis of the feedback from the output values. The fuzzy controller maintains the corresponding value while controlling the process control variables. When the current value is less than the desired value, Fuzzy logic controller sets a new value for the set point PID flow rate controller. The new value of current set point is decided by the difference between the current value of the plant reactor and the desired value. The overall diagram is shown in Figure 4.

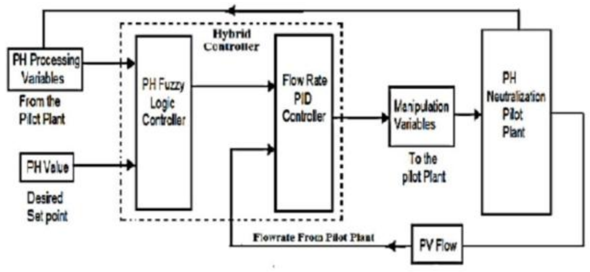

Fig- 4: Logical Diagram for Fuzzy based PID Controller

Fuzzy logic controller gives better result for large continuously changing pH process parameters. Fuzzy Model (FM) describes the human intelligent knowledge and excellent pH control experience of expert operator without mathematical format. FLC is a powerful alternative to the conventional methods and is suitable and convenient as it directly deals with non-stationary and uncertain behavior of pH process [15]. Comparison with conventional PID control shows that FLPC has smooth control even against accidental disturbances within the process. Fuzzy Logic algorithms show great promise in its ability to handle the linearization job on the pH process for the PID controller to work on. The fuzzy logic concept bases itself on membership sets that may or may not intersect (indicating the degree of uncertainly) and assigns "weights" to each set depending on the human controller [16]. **Fuzzy** PI Controller works well within required operating conditions.

Sebastian George and Devendra N. Kyatanavar [17] has studied neutralization process using Fuzzy logic P+I controller. The set point of the desired pH value is defined manually while other process control variables are controlled automatically based on the information coming from the plant output. Fuzzy logic controller is maintained corresponding pH value while manipulating the process control variables. When the current pH value is less than the desired value, Fuzzy logic controller sets a new point for the P+I valve flow rate controller. The new value of current set point depends upon the difference between the current pH value of effluent juice and the desired value. Hybrid Fuzzy Logic P+I controllers is much better when compared to classical controllers to control those processes which are highly non-linear and where the analytical model is not well known [18]. Design of fuzzy logic controllers encounters difficulties in the selection of optimized membership functions and fuzzy rule base, which is traditionally achieved by a tedious trial-and error process. Genetic algorithms for automatic design of high performance fuzzy logic controllers using sophisticated membership functions that intrinsically reflect the nonlinearities encounter in many engineering control applications [19].

Juan Chena[20], combines the fuzzy control and sliding mode control (FSMC), and fully using the system state information to simplify the fuzzy control rules. The quantification scale factor changing adaptively adjusts the universe of fuzzy control system, makes system control signals soften and reduces the chattering of sliding mode control. Designed control system has strong robustness and good adaptive ability which shows that even a major change in operating point or suffer greater interference, the systems still have good anti-disturbance and strong robustness. Ranganath Muthu [21], has designed PI controller and fuzzy logic controller (FLC) for a simulated pH neutralization process. And result shows that the FLC is able to control the pH neutralization process better as compared to PI controller. Fuzzy PI Controller works well within required operating conditions. The servo problem response was quick with no overshoot and oscillations when tested with random uniform set points from pH=3 to pH=14. The results of the Fuzzy PI Controller when subjected to regulator disturbances are satisfactory and oscillation levels due to disturbances are at very minimal values: <0.01 pH units for load disturbances at 10% of Fa (flow rate of influent), and <0.035 pH units for load disturbances at 40% of Fa[22].

Jakub Novák and Petr Chalupa [23] has formulated a Model Predictive Control (MPC) based on the fuzzy representation of the nonlinear process. MPC based on fuzzy estimation of the states and unmeasured disturbances was applied to simulated pH neutralization process. The process model of each Kalman Filter is augmented with the disturbance model in order to remove steady-state error in case of model-plant mismatch or unmeasured disturbance. Control performance of the proposed fuzzy estimation scheme with MPC based on multiple models is comparable to the performance obtained when a computationally demanding nonlinear optimization procedure is used online at each sampling instant within a nonlinear MPC controller. T-S fuzzy model is an essential nonlinear model, and it can approach a nonlinear system infinitely. The universal approximation of T-S fuzzy model for the nonlinear system provides the theory basis to identify the nonlinear system by using T-S fuzzy model. The use of T-S fuzzy model to describe the rationality and efficiency of pH neutralization process can realize the online identification of related parameters better. [18].

3.ARTIFICIAL NEURAL NETWORK BASED CONTROLLERS

The ever increasing technological demands of our modern society require innovative approaches to highly demanding control problems. Artificial neural networks with their massive parallelism and learning capabilities offer the promise of better solutions, at least to some problems. The control community has heard of neural networks and wonders if these networks can be used to provide better control solutions to old problems or perhaps solutions to control problems that have withstood our best efforts[24].

Neural networks research has spread through almost every field of science, covering areas as different as character recognition, medicine, speech recognition and synthesis, image processing, robotics and control systems. This means that, for the large majority of researchers, artificial neural networks are a new and unfamiliar field of science.

The artificial neural network predictive controller outperformed the conventional controllers, in terms of achieving faster settling time, less controlled variable deviation and smoother manipulated variable behavior. However, this controller has some disadvantages in terms of its complexity and the time-consuming tuning approach, since a systematic way for tuning has yet to be established. Mohamed Gaberalla Mohamed Khair Elarafi, Suhaila Badarol Hisham[25], illustrates feasible modelling of the pH neutralization plant using empirical techniques and investigates the performance of an artificial neural network predictive controller against the more traditional PID controllers. As a conclusion, a feasible empirical model was found closest to a second–order with dead time. The artificial neural network predictive controller has outperformed the conventional PI / PID controllers.

The Neural Network Predictive Controller (NPC) consists of two major parts that predict the performance of the plant for specific time horizon - (i) the Neural Network System Identification and (ii) the Predictive Controller. Neural network is used to represent the forward dynamics of the plant. The prediction error between the plant output, y_p, and the neural network output, y_m is used as the neural network training signal as shown below in Fig. 5.

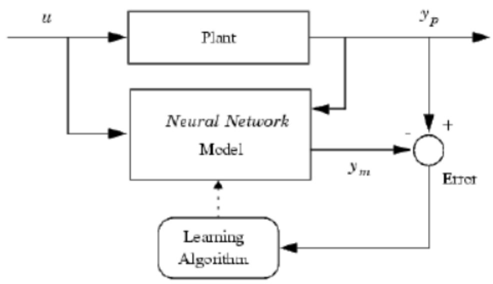

Fig- 5: Neural Network System Identification

The neural network plant model uses previous inputs and previous plant outputs to predict future values of the plant output. This network can be trained offline in a batch mode by using data collected from the operation of the plant (fig. 6).

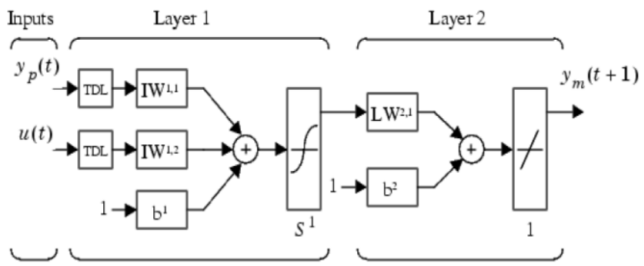

Fig -6: Neural network Structure

The neural approach to computation has emerged in recent years to tackle problems for which more conventional computational approaches have proven ineffective. Such problems arise when a computer is asked to interface with the real world, which is difficult because the real world cannot be modelled with concise mathematical expressions. Problems of this type are machine vision, speech and pattern recognition, and motor control [26] [27].

The neural network controller has a number of distinct advantages over standard nonlinear model predictive control. In analogy with other explicit MPC methods, the neural network controller has substantially reduced on-line computational requirements. In addition, the computational effort involved in the network training depends mainly on the network complexity, and not on the length of the control horizon. This makes it feasible to design controllers with a longer control horizon than might be possible in MPC.[27]. Pouya Bashivan, Alireza Fatehi, Ehsan Peymani[28] has developed a multiple-model adaptive controller using the Self-Organizing Map (SOM) neural network for pH neutralization plant. An improved switching algorithm based on excitation level of plant has also been suggested for systems with noisy environments.

Mincho Hadjiski[29] has used eight different feed-forward Neural Networks (NN) to cover a variety of functions in control systems: First principle model emulation in order to overcome computational restrictions, non-measurable disturbances estimation, gain scheduling tuning of standard PID controller parameters, feed-forward control action formation, time delay compensation by NN-based prediction. Author has implemented conventional Feedback (FB) control structure, Cascade control (CC),FB control with gain scheduling (FBGS),Cascade control with gain scheduling (CCGS),Internal Model Control, Feed- forward control (FF),Combined feed-forward feedback control (FFIFB)without gain scheduling, controllers for pH neutralization.

Neural network approximation of nonlinear model predictive controllers [30] achieve good control performance with this approach, reducing the required on-line computations significantly. The accuracy required of the controller approximation in order to ensure closed-loop stability has been assessed by computing the robustness of the closed loop with respect to controller perturbations. In RBF neural network, the mapping between the input layer and the hidden layer is constructed by Gaussian radial basis function, and the mapping between the output layer and the hidden layer is constructed by linear function. The activation function of the hidden layer nodes locally responds to input signal. That is to say, its activation is maximal when an input is located at the RBF center, while the activation decreases monotonically when the distance between the RBF center and an input increases. Building and training of RBF neural networks model and simulating the dynamic behavior of the pH neutralization process is an good alternative and feasible way for the fault diagnosis of complex dynamic processes with strong nonlinearity[31].

Xiaodong Yu, Dexian Huang, Xiong Wang and Yihui Jin [32] has proposed an effective nonlinear model predictive control (NMPC) algorithm based on Differential Evolution (DE) and Radial Base Function (RBF) neural network. RBF neural network is used for the modelling. W. Luo, A.J. Morris, M.N. Karim, E.B. Martins and T. Hong [33]developed an adaptive radial basis function network, RBFN, is by the adaptive training of a RBFN using the online model selection and parameter estimation algorithm, GFEX, Givens rotation with Forward selection and EXponential windowing. The GFEX algorithm has been combined with mechanisms which automatically generate and eliminate radial basis function centers to form adaptive radial basis function networks (RBFN).

4. CONCLUSION

Control problems of pH neutralization process reveal several difficulties mainly due to their highly nonlinear characteristics. Each pH neutralization plant should have a specific control strategy according to its characteristics and desires. There are various successful control strategies being applied for pH neutralization problems. Generally we used PID or PI controllers but they are not capable to adapt online changes or nonlinear behavior. For controlling the pH neutralization process, diverse control strategies have been researched and developed for many years. For such a nonlinear control process adaptive control strategies are developed such as fuzzy logic, neural network, Genetic algorithm, neuro-fuzzy, Model predictive control, NARX control. However it is still difficult to determine the suitable approach to be applied in specific pH plant. Therefore, the most adequate algorithms and control strategies should be designed and chosen to obtain ideal control system that will perform in critical environment.

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