A Review on Temperature Compensated pH Monitoring and Control System for Process Industries

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Abstract— pH is a unit of measure, which describes the degree of acidity or alkalinity of a solution and is very important parameters for several process industries like pharmaceutical industry, paper industry etc. This paper describes the importance and application of pH monitoring system. Also, challenges present in the conventional techniques are discussed and the need of a new modern pH monitoring system is presented in this article. We also propose a novel modern technique for the monitoring and control of pH in the industries.

Index Terms— Active pH monitoring, paper industry, pharmaceutical industry, effect of temperature variations on pH measurement, electrode placement and maintenance.

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1 INTRODUCTION

pH is a unit of measure, which describes the degree of acidity or alkalinity of a solution. It is measured on a scale of 0 to 14. The term pH is derived from “p”, the mathematical symbol of the negative logarithm, and “H”, the chemical symbol of Hydrogen. The formal definition of pH can thus be stated as the negative logarithm of the Hydrogen ion activity. Mathematically, it can be written as:

$$pH = -\log [H+] \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

The pH value of a substance is directly related to the ratio of the hydrogen ion [H+] and the hydroxyl ion [OH-] concentrations. If the H+ concentration is greater than OH- concentration, the material is acidic in nature i.e., the pH value is less than 7. On the other side, if the OH- concentration is greater than H+, the material is basic i.e. alkaline in nature, with a pH value greater than 7. If equal amount of H+ and OH- ions are present, the material is taken as neutral in nature, with a pH value equal to 7 [1,3].

2 pH MEASUREMENT

A rough indication of pH can be obtained using pH papers or indicators, which change colour as the pH level varies. These indicators have limitations on their accuracy, and can be difficult to interpret correctly in coloured or murky samples.

More accurate pH measurements are obtained with a pH meter. A pH measurement system consists of three parts: a pH-measuring electrode can be thought of as a battery, with a voltage that varies with the pH of the measured solution. The pH measuring electrode is a hydrogen ion sensitive glass bulb, with a mV output that varies with the changes in the relative hydrogen ion concentration inside and outside. The reference electrode output does not vary with the activity of the hydrogen ion. The pH electrode has very high internal resistance, making it difficult to measure the voltage change with pH. The input impedance of the pH meter and the leakage resistance are therefore important factors. The pH meter is basically a high impedance amplifier that accurately measures the minute electrode voltages and displays the results directly in pH unit either on an analog or a digital display system. In some cases, voltages can also be read for special applications or for use with ion-select or Oxidation-Reduction Potential (ORP) electrodes.

Temperature compensation is contained within the instrument, because pH electrodes and measurements are temperature sensitive. The temperature compensation may either be manual or automatic: with manual compensation, a separate temperature measurement is required, and the pH meter manual compensation control can be set with the approximate temperature value. The signal from a separate temperature probe is fed into the pH meter with automatic temperature compensation (ATC), so that it can accurately determine pH value of the sample at that particular temperature.

Buffers are solutions bearing constant pH values. They have ability to resist changes in that pH level. They are used to calibrate the pH measurement systems (electrodes and meters). There can be small differences between the output of one electrode and another, as well as changes in the output of electrodes over a passage of time. The systems must necessarily be calibrated periodically.

The block diagram for pH monitoring is shown in fig.1. In this process of tank C – 30 we keep on monitoring the pH of the broth and maintained it on the prescribed set point. For this process of continuous monitoring we require the following basic components:

- *Sensor/Electrode:* The pH sensor also called electrode is a device, which actually senses the pH of the material to which it is subjected. In this process one require to monitor the pH of the broth. The electrode generates electric signal in the form of millivolt corresponding to the pH of the broth. The pH electrode is actually a small battery (technically a transducer). This battery displays a varying voltage, depending upon the pH value of the solution in which it is immersed.
- *pH Transmitter:* A transmitter is a high input impedance operational amplifier. Thus it amplifies the signal generated by the sensor, which is high impedance millivolt signal and also convert that signal into a 4 to 20 mill ampere current

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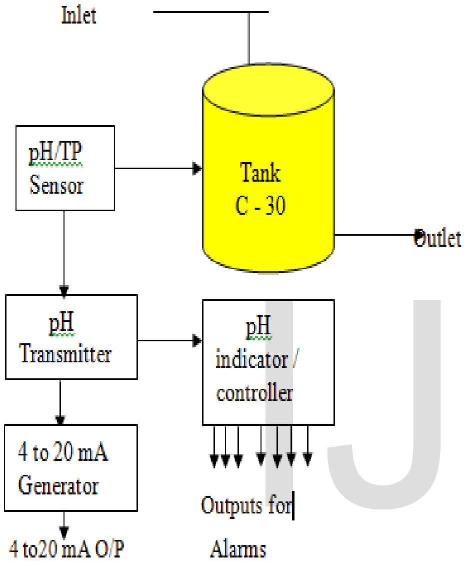
signal so that it can successfully drive the further stages of measurement system. The need of a transmitter arises when the process is more than 50 feet from the controller, and the line loss from a high impedance electrode is too great to transmit useful information. And after amplification the 4 to 20 mA signal can be sent thousands of feet without any loss of information.

- *Digital pH Indicator:* A digital pH indicator is used to display the measured value of pH.
- *4 to 20 mA Signal Generator:* This is a circuit that converts the mV signal coming from the transmitter into current signal ranging from 4 mA to 20 mA (industrial standard signal). We can directly display the mV signal on a digital display unit as explained above, but for further use of measure signal we need to convert it into current signal for application like activating various alarms, to operate the control valves etc.



3 pH CONTROLLING TECHNIQUES

Accurate measurement and control of pH is a common requirement in industrial plants. Application includes monitoring of cooling tower water, boiler, feed water, process steam, waste treatment, and plant effluents. Control of pH is dependent on measurement reliability, and proper measurement requires an understanding of the basic principles.

- *Batch control:* It is normally used when the total volume of the solution to be treated is relatively low, such as in waste treatment process where liquids can be collected efficiently and treaded in tanks. The amount of reagent required for titration curve, tank volume, and reaction time slow reagent addition rates and good storing permits more accurate control with less likelihood of pH overshooting.
- *Continuous control:* It is similar to batch control except that there is a continuous flow of influent and treated effluent, fig. A proportional controller may require regulating reagent flow rates if influents pH varies widely

4 LIERATURE REVIEW

The investigator has carried out a thorough literature review and has under taken an extensive study on temperature compensated pH measurement. Some of the literature contents have been discussed below:

Min Han et al in [1] have presented an adaptive algorithm of universal learning network and its application to identify pure time delay of a plant model. Universal learning network can be used in model predictive control for stabilizing a class of nonlinear systems with long time delay. The control architectures are introduced and applied to pH measurment process. Simulation results into the applicability and effectiveness of the measurement.

Audin Faanes et al in [3] have presented control related design issues for process plants. Mainly for control reasons, the neutralization is usually performed in several steps (mixing tanks) with gradual change in the concentration. The aim is to give recommendations for issues like tank sizes and number of tanks. Assuming strong acids and bases, we derive linearized relationships from the disturbance variables (e.g. inlet concentration and flow rate) to the output (outlet concentration), including the scaled disturbance. With local PI or PID control in each tank, it is recommended to use identical tanks with total volume .

Ayla Altinten in [4] generalized predictive control applied to a pH neutralization process. The process consists of a continuous flow tubular reactor. The process stream is a water solution of acetic acid and the titrating stream is a water solution of sodium hydroxide. The aim of the control is to keep the pH value at a given set point value when the process is subjected to variations in feed flowrate. Even the pH monitor can solely display the parameters only.

J. Barraud in [5] reviewed the problem of controlling the pH in a fed batch reactor where precipitation occurs. Due to the batch nature of the production and the effects of precipitation, the control problem is rather different from the well studied cases of continuous processes, which are usually considered under the assumption of perfect solubility. To fulfill this objective a laboratory reactor used to produce precipitates, a simple control strategy is proposed, which is consistent with the limitations of the apparatus. Interestingly, the reagents under consideration have well known specifications. This point is advantageously taken into account to identify a single-input–single-output model offline. Finally, simple rules are proposed to deal with precipitation. Representative experimental results obtained on the reactor are presented to prove the relevance of the approach.

Skogestad, S, in [6] represents analytic rules for PID controller tuning that are simple and still result in good closed-loop behavior. The starting point has been the PID/ON-OFF tuning rules that have achieved widespread industrial acceptance. The rule for the integral term has been modified to improve disturbance rejection for integrating processes. Furthermore, rather than deriving separate rules for each transfer function model, there is a just a single tuning rule for a first-order or second-order time delay model. Simple analytic rules for model reduction are presented to obtain a model in this form.The control system with analog output can be hooked to recording systems if required.

Alex D et al in [8] proposed the control of pH processes based on the Wiener model (a dynamic linear element representing the mixing dynamics of the process in series with a static nonlinearity). Conditions under which the pH process behaves like an exact Wiener system are examined. Linearization is employed to make the pH process appear linear enabling the application of a linear feedback (PI) controller. Although many others have utilized an identified nonlinearity for linearizing feedback control of pH processes, much less work has been done on using the nonlinearity for linearizing feed forward control. Here, a simple linearizing feed forward controller is proposed. Simulated closed-loop results demonstrate the superiority of the linearizing feed forward–feedback strategy versus linearizing feedback only.

S. Regunath, V. Kadirkamanathan in [9] provides more information for controlling , pH neutralisation process has been developed in this paper. This method is applied to a weak acid–strong base neutralisation process. The objective of the control effort is to maintain the pH in the presence of severe load changes in the influent composition and/or flow rate. Experimental results are given, that demonstrates improved performance is achieved by the proposed controller. The implementation of this method has lead to a high performance pH controller, which has a simple structure and does not demand significant computing resources.

S. Shobana et al in [11] claimed control of pH, particularly, in industrial application, is difficult and challenging due to its time-varying and nonlinear nature of the chemical or biological process. This non-linearity does however suggest that pH control would be a suitable application area for a model based double-control system, whose ability to handle non-linearity is well known. The mathematical model of pH for a weak acid-strong base is used to design PID double-controller scheme which provides outstanding set point tracking and disturbances rejection simultaneously to control pH processes.

S. B. Mohd Noor et al in [12] established that Industrial processes produce a variety of waste water pollutants, some are difficult and/or costly to treat. Waste water characteristics and level of pollutants vary significantly by industry. The task of various pH control system is to adjust the pH of the process stream into the defined acceptable discharge range. It is having no information about the impact of temperature on pH measurement.

Omar Galán et al in [13] contributed towards the real-time implementation of a set of multi-linear model-based control design methodologies for pH neutralization system that exhibits nonlinear dynamics. Further the study does not include any solution for chemically hazardous area related pH
measurement. No hazardous area classification is part of study.

Sanaz Mahmoodi et al in [14] added that Laguerre filters and simple polynomials are used respectively as linear and nonlinear parts of a Wiener structure. The obtained model structure is the so-called Wiener–Laguerre model. The fitness of this model according to variance account for (VAF) criterion is 92.32%, which is completely acceptable for nonlinear model predictive control applications.

Chaiwat Waewsak et al in [15] contributed towards neural-fuzzy control system for anaerobic hybrid reactor (AHR) in wastewater treatment and biogas production still overload influent feeding and the recovery phases need to be monitored.

Naohiro Kishida et al in [17] made Two bench-scale sequencing batch reactors (SBRs) operating in a fixed hydraulic retention time study to investigate the effectiveness of oxidation-reduction potential (ORP), pH and dissolved oxygen as parameters for indicating denitrification followed by nitrification in SBRs for swine wastewater treatment. Temperature compensation is missing in the study.

Fangwei Xu et al in [18] suggested that due to the process time delays, the closed-loop response can be divided into feedback control invariant part and feedback controller dependent part. A significant feature is that the output variance/covariance upper bound constraint can be explicitly specified according to the product specifications and is always satisfied when the problem is feasible. This desired structured closed-loop response can thus be served as a benchmark against which the existing controller performance can be compared.

C.H. Ga et al in [19] evaluated the feasibility of real-time control using the pH (mV)-time profile in a sequencing batch reactor for swine wastewater treatment , and the characteristics of the novel real-time control strategies were analyzed in two different concentrated wastewaters. Successful real-time control using the developed control strategy was achieved despite the large variations in the influent strength and the loading rate per cycle. When the flow is constant and agitations are uniform in tank on-off pH control can contribute to the accurate measurements. Calibration Methodology was missing.

Shengbing Duan et al in [20] developed an on-line adaptive control strategy based on DO/pH measurements and artificial neural network pattern recognition (ANNPR) model for fed-batch cultivation processes . Based on the on-line measured pH and DO data, the recognition results on current physiological state was deduced by the ANNPR models, and then the on-line adaptive control of nutrient feeding rate was implemented. The control strategy is potentially useful for high cell density cultivation of recombinant microorganisms to efficiently express value-added foreign proteins or enzyme.

Ari Ingimundarson et al in [21] shown, how the tuning of a loop is used to commission a closed-loop performance monitoring method. . The impulse response is obtained from the tuning of the loop. All parameters of the monitoring method are set by using the impulse response. The presented method works equally well when disturbances are stochastic or deterministic. Maintenance of control equipments plays a major role in accurate measurements. This aspect is not taken into consideration while analysing the response.

Carlos R. Alvarez et al in [6] contributed that Quality control and safety related issues have become more and more important in industrial production of high added value products and chemical specialities.Results show that the new approach can be successfully applied to monitor this kind of processes since it works well during both fault detection and identification stages.

Chao-Chin Chung et al in [8] added that regulation of pH value is an important issue in the Pharma industry for quality production. A pH process sometimes has non-linear dynamics with system uncertainty. This study treats the pH regulation process of a reactor tank as a grey box with partially known system information. A fuzzy controller takes the prediction together with the current system response to regulate the discharge of base (NaOH) or acid (HCl) solution into the reactor tank to arrive at a desired pH value.

Yoon Keun Jung et al in [24] contributed sensor development for the measurement of buffer capacity and alkali consumption rate from the pH response signals generated by an automatic pH controller. On-line measurement of the two parameters was demonstrated in the cultivation of *Escherichia coli* in a 5-*l* jar fermentor which can formed as basis for High scale production batches.

Dirk Weuster-Botz et al in [25] supported in his study an intermittent feeding system for shaking-flasks was developed to close the gap between batch operated shaking-flasks and fed-batch operated pH controlled stirred tank reactors. Physiological effects of an intermittent feeding were studied in a stirred tank reactor which expressed the need of uniform agitations for accurate measurements.

5 CONCLUSIONS

Based on the thorough literature review we envisages the following conclusions:

- pH-Control system can be based on ON/OFF Control theory.
- pH-Control can be devised, even based on PID Principles.
- Implementation of novel criteria for involving application of the pH monitor/controller in hazardous area to make it flame-proof still a challenging issue.
- Temperature variations in a process affects the pH measurement .
- Elctrodes placement and their maintenance is also a challenging issue.
- A complete automatic sytem is required which considers all the issues like electrode placement and their maintenance, effect of the temperature variations, and inbuilt caliberation system.
- pH-Monitoring can be solely used for parameters display only.
- The control System with output can be hooked to recorder further.
- The control System if does not include Temperature Compensation the measurement can be error prone.
- The chemically hazardous areas ,need to have flame proof housing for pH monitoring system.

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