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Design and Simulation of PID Controller for PH Neutralization Process

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Abstract: ***PH control system plays an important role in a wide range of industrial applications particularly in wastewater treatment management. Untreated wastewater generally contains high level of organic materials, numerous pathogenic microorganisms which raised concern in environmental and health hazards. The high non-linearity and time varying in pH neutralization process and the uncertainty of the plant dynamics are the key challenges of the pH control systems. There are many sophisticated PID tuning method, however conventional tuning procedure remains effectives in industries. The overall control scheme involves controls of flow rates of acid and base solutions. Ziegler Nichols method tuning has been developed for first order and second order system, in which, also applicable for pH neutralization control model. This paper elaborates the performance of transient response for pH neutralization process by using empirical techniques through the simulation software along with Proportional-Integral-Derivative (PID) for controlling purpose. A result of comparison between Ziegler-Nichols versus First Order plus Time Delay (FOPTD) of pH control system design for PID controller is seeing in a graph.***

Index Terms: PID control, PH neutralization, ZN tuning.

I. INTRODUCTION

Process control tasks in chemical process industry such as pharmaceutical industry, biological reaction, and wastewater treatment becoming more challenging over the years. One of common process control task involves in these industries is pH neutralization and concern in this issue is increasing and become enormous due to environmental impact [1].

Industrial waste which normally treated using conventional wastewater treatment plant is rarely neutral.

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Due to increasing environmental demand, treated industrial waste using wastewater treatment plant has to be neutralized before discharge or reuse [2].

Furthermore, the control of pH neutralization process has become harder and more difficult problems due to the complex non-linearity, time invariant and time delay in the process flow.

Many studies have been conducted to identify suitable control scheme for high nonlinear system, particularly for pH neutralization process. The first research question is to identify an efficient controller tuning rules. Despite the popularity of conventional control scheme, an efficient controller tuning rules in required due to challenging demand to achieve pH set point.

The second problem is the poor performance in conventional control scheme which has effect and downgrade the performance of the systems [3]. To solve both issues, a good dynamic model for pH neutralization process has to be identified and analyzed for further computation in industrial controller.

Ziegler-Nichols (ZN) tuning methods is one of the most well-known and most widely used tuning rules due to its simplicity and satisfactory performance for many first order plus time delay (FOPTD) and second order plus time delay (SOPTD) system. Nevertheless, the ZN tuning method may be resulting large overshoot and oscillatory response and the parameters of the step response may be hard to determine due to measurement noise [4].

However, many studies show ZN tuning implementation in pH neutralization process control have a lower value for settling time [5]. In contrast, this method also provides quicker and easier tuning rules compared to other tuning methods.

In addition, ZN method may drives the system process into marginal stability and also performs fast recovery from disturbance but leads to oscillatory response.

The highlight of this research is the simulation result for PID controller design and its tuning parameters.

Results on several tuning parameters is plot and the transient response is analyzed in term of overall controller performance. PID controller is chosen for pH neutralization simulation system due to ability to control the variable due to high non-linearity characteristic, time-varying, sensitivity to small disturbance and more practical oriented [6]. For all that, PID controller design and setting in this simulation study resulting reliable control system and safely achieve high pH neutralization performance of operation process.

II. LITERATURE REVIEW

A considerable amount of studies has been published on PID controller parameter tuning for various control system application. These studies highlighted good control performance and acceptable transient response on most linear problem. PID controller has been proven high reliability and robustness in controlling process variables such as temperature, flow rate, pressure, tank level, etc. In addition, the most common factor that attract industry to use PID controller because of lower start-up cost, simplicity in its control structure, easy to maintain and easy to understand by the user [7].

Even so, improper PID parameters tuning may lead to the performance cyclic and slow recovery, poor of robustness and the unpleasant scenario which possibly contribute to collapse of the process system [8]. In spite of the fact that, this case had led many researchers to explore the superlative method in searching optimum PID parameters.

Numbers of strategies have been proposed to determine the optimum setting for PID controllers. Ziegler-Nichols method is one from among of groundbreaker in PID tuning methods process. Researchers have proposed experimental PID tuning method process based on trial and error and based on the performance of reaction curve [8]. Nevertheless, there are some difficulties may come to pass in order to tune PID controller when the systems in a complex way such as high nonlinear process, time delay, non-minimum phase and high order. Unfortunately, Ziegler-Nichols method may give overshoot, highly oscillatory, and longer settling time for a high order systems and this could lead the process to have undesired set point value [9]. Therefore, there is an urgent need to find efficient control rule specific to tune PID parameter.

The probation of PID controller to minimize the error by adjusting the process by using the manipulated variable. The controller may have different structures and methodologies for designing the process in order to achieve the target or desired performance level. Qinhui Wu and Zongze Cui has proposed PID controllers when were used alone, it can give a poor performance [10]. PID loop gains must be reduced so that the control systems does not overshoot, oscillate or hunt about the control set point value. They also have difficulties in the presence of non-linearity, may trade-off regulations versus response time, do not react to changing process behavior and have lag in responding to large disturbances. These studies highlighted good control performance and acceptable transient response on most linear problem.

III. METHODOLOGY

The simulation settings and reaction model is based on Strong Acid and Strong Base pH neutralization process using continuous stir tank reactor (CSTR) with assumption mixing is complete and perfect [11]. First, the simulation is considering the molarity and concentration of Sulphuric acid (H_2SO_4) and Sodium Hydroxide ($NaOH$) to neutralize and give a neutral pH value to the process system. Two points have been emerged in development the pH neutralization process in order to model the nonlinearity of the process.

First point is material balance in terms of hydrogen ion (H^+) and hydroxyl ion (OH^-). The second point is the material balance in terms of all the atomic species and all addition equilibrium relationship is performed [12]. The simulation is run and expected to mimic physical experiment in practical implementation and testing with real time to get the exact results as the set point value. The stirring dynamic is given by equation:

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

$$H_2SO_4 + NaOH = Na_2SO_4 + H_2O \quad (2)$$

$$2H_2SO_4 + NaOH = Na_2SO_4 + 2H_2O \quad (3)$$

$$[Na^+] + [H^+] = [SO_4{}^{2-}] + [OH^-] \quad (4)$$

$$[H^+].[OH^-] = k_w = 10^{-14} \quad (5)$$

$$X = [OH^-] - [H^+] \quad (6)$$

$$X = [Na^+] - [SO_4{}^-] \quad (7)$$

To measure the error value in the process, PID controller is used to calculate the difference between a measured process variable and desired set point. In formation of control parameters for optimum values, tuning methods is used for the desire response. In addition, the needs of criteria for PID control is the stability to fulfill the limitation and it must be satisfy the complex principle of the system.

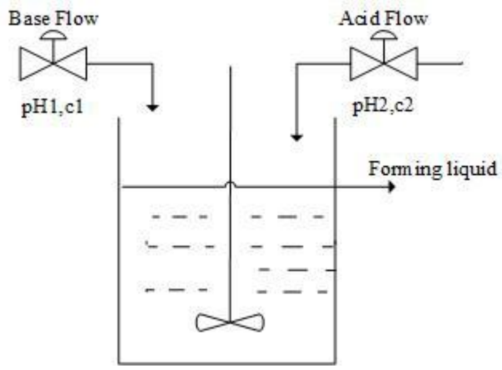

Fig. 1 pH neutralization process using CSTR

IV. CONTROL SYSTEM MODELLING

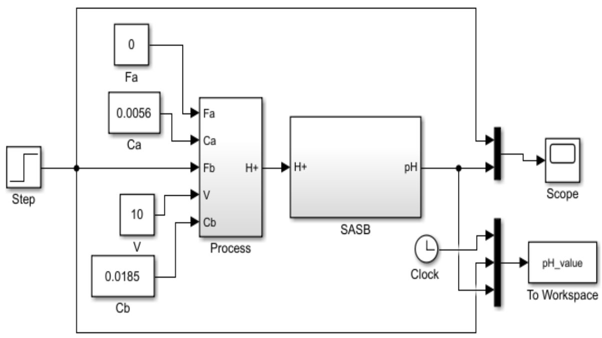

Fig. 2 The block simulation

Mathematical model is based in this empirical research study, strong acid and strong base with 1 Molarity is prepared to conduct the experimental data process. Experiments were conducted on an acidic solution of sulfuric acid (H_2SO_4) neutralized using a continuous flow of sodium hydroxide ($NaOH$) solution to obtain empirical data.

The system is modeled with general transfer function as First Order plus Time Delay (FOPDT) and it obtained from the open-loop responses as given in Equation (1) and Equation (2).

$$G\ (s) = \frac{Ke^{-\tau_d s}}{\tau s+1} \tag{1}$$

Assume the FOPDT utilize from [13], the transfer function is expressed by Equation (2).

$$G(s) = \frac{2.453e^{-8.802s}}{0.6374s+1} \tag{2}$$

From transfer function in Equation (2), the transfer function parameters can be defined as,

$$K_p = 2.453, \tau = 0.6374, \theta = 8.802s \tag{3}$$

Control performance of PID controller are examined by MATLAB simulation by using the first order transfer function. In this paper, Ziegler-Nichols tuning method based on step response of plant is used as the PID controller tuning as it is the best method which gives higher and better stability for the pH neutralization process.

V. RESULTS AND DISCUSSION

In the simulation environment, the closed-loop transfer function for pH neutralization is simplified to FOPTD. The Simulink block diagram is shown in Figure 2. A simulation has been done by using the first order transfer function given. The simulation result is taking from the MATLAB simulation work which carried out for the PID controller designed. The servo response is shown in Figure 3 and the time domain is calculated.

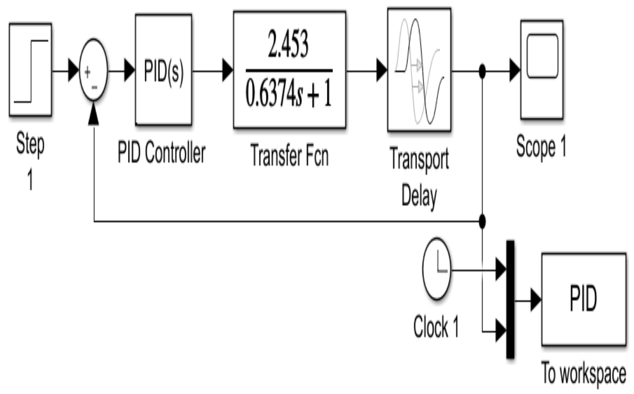

Fig. 3 Block diagram of transfer function

Table. 2 Tangent line indicate the time delay and time constant

Time delay	8.8020
Time Constant	0.6374

PID controller are designed and the time domain analysis resulting improve rise time and settling time for the process. Also, the comparison result indicate good response and higher stability for the process represented with a minimum rise time and settling time in order to achieve the desired response. With the value of Kc, Ti and Td given in Equation (3), result from step response of Z-N tuning method is obtained using MATLAB Simulink as shown in Figure 3. From Ziegler-Nichols tuning method based on step response formula, Kc = 0.086, Ti = 17.6s and Td = 4.4s.

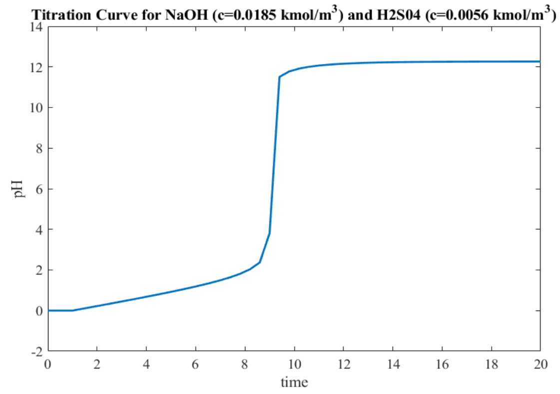

Fig. 3 (a)

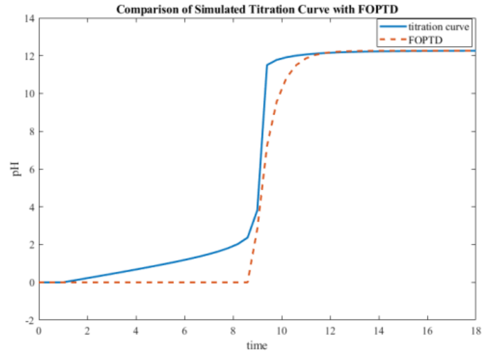

Fig. 3 (b)

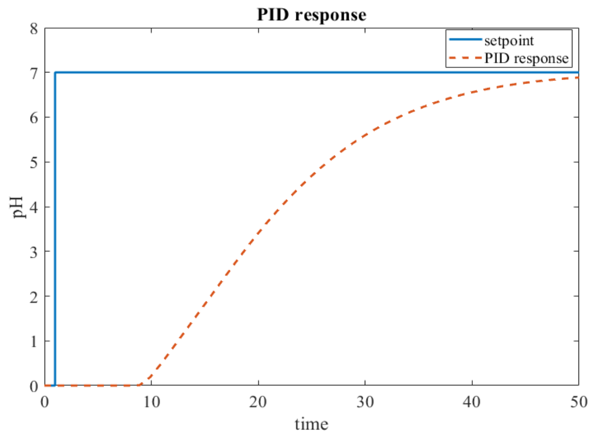

Fig. 3 (c)

On top of that, the result shows that the steady state error and overshoot are in a good response. The transient response is also in a smaller value which were acceptable for the performance of pH neutralization process due to high nonlinearity and instability of the chemical process.

VI. CONCLUSION

This paper present the response of PID controller design by using Ziegler Nichols tuning method compared with the First Order plus Time Delay (FOPTD). From the result shown, it is identified that the performance of Ziegler-Nichols response for pH neutralization process is faster. This suggests that Ziegler-Nichols tuning method is good for initial estimate of parameters such as reaction curve method and it can be used

Confidently for majority of systems which confirms again wide applicability of this method.

For future work, this study can be enhanced into two parts which are run the simulation testing at the actual plant and also designing the real-time process controller for pH neutralization process system.

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