PID TUNING FOR pH NEUTRALIZATION PROCESS

Course: Process Dynamics and Control

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1 INTRODUCTION

pH control is one of the most challenging aspects in chemical process industries due to its highly nonlinear behavior. Maintaining the pH value at a desired setpoint is critical in applications like wastewater treatment, chemical reactors, and fermentation processes. Our project focuses on designing and tuning a PID controller to regulate the pH value of a neutralization process under various operating conditions. The primary objective is to achieve stable pH control at a setpoint of 8 while handling disturbances in feed concentration and flow rate.

2 PROCESS DESCRIPTION AND TRANSFER FUNCTION

The pH neutralization process involves mixing an acidic or basic stream with a neutralizing agent to achieve the desired pH level. The process exhibits first-order dynamics with transport delay.

2.1 Transfer Function and Block Diagram

The system is represented by:

$$G(s) = \frac{14s + 25}{1478.26s + 1} \tag{1}$$

The numerator coefficients $(14s + 25)$ represent the process dynamics where the coefficient 25 indicates the steady-state gain (how much pH changes per unit change in manipulated variable), and the zero at $s = -1.79$ provides lead behavior for improved response. The denominator time constant $\tau = 1478.26$ seconds reflects the slow dynamics typical of pH neutralization due to mixing requirements and reaction kinetics. Transport delay accounts for pipe length, residence time, and mixing lag. Measurement noise simulates realistic pH probe behavior.

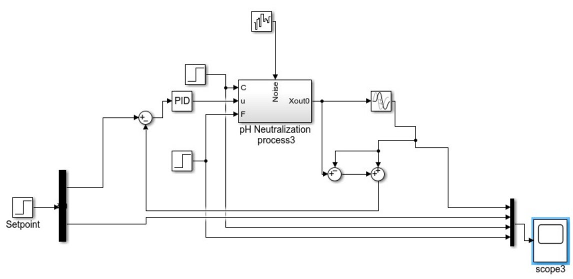


Figure 1: Block diagram of PID controller for pH neutralization process

2.2 Initial Parameter Estimation

The baseline PID parameters were determined using the **Ziegler-Nichols closed-loop method**. This approach identifies the ultimate gain (K_u) and oscillation period (P_u) at which the system becomes marginally stable under proportional-only control.

For the given transfer function, the ultimate gain was estimated as $K_u \approx 48$ with an oscillation period of $P_u \approx 100$ seconds. Applying Ziegler-Nichols tuning formulas:

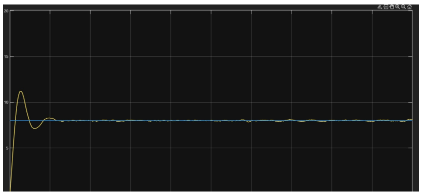
$$K_p = 0.6 \times K_u = 0.6 \times 48 = 28.8 \approx 29 \tag{2}$$

$$K_i = \frac{1.2 \times K_u}{P_u} = \frac{1.2 \times 48}{100} = 0.58 \tag{3}$$

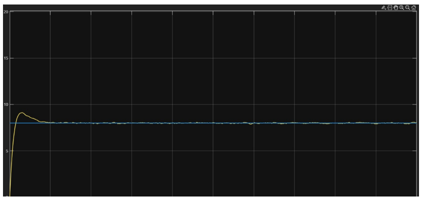
$$K_d = 0.075 \times K_u \times P_u = 0.075 \times 48 \times 100 = 360 \tag{4}$$

However, for pH processes with measurement noise, the derivative gain was reduced significantly to $K_d = 2$, and the integral gain was increased to $K_i = 2$ for better steady-state error elimination. These adjustments yielded the baseline configuration: $K_p = 29$, $K_i = 2$, $K_d = 2$.

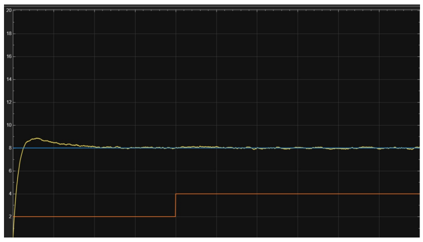
3 RESULTS AND ANALYSIS



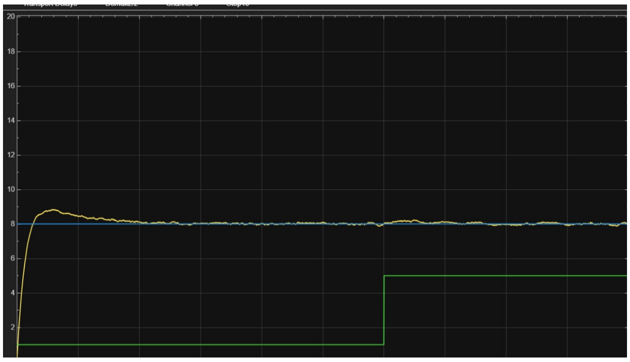
(a) Without IMC



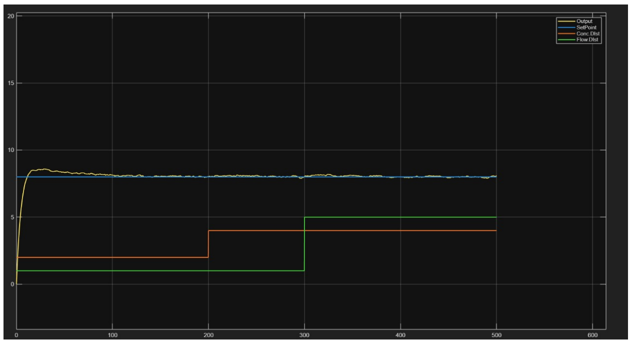
(b) With IMC



(c) Concentration disturbance



(d) Flow rate disturbance (400%)



(e) Combined disturbances

Figure 2: pH response under different scenarios

(a) Without IMC: Shows initial sharp transient with quick settling. **(b) With IMC:** Internal Model Control provides smoother response with minimal overshoot. **(c)** Concentration disturbance handled with higher $K_d = 10$ for damping. **(d)** Flow rate disturbance requires $K_d = 11$ for effective rejection. **(e)** Combined disturbances demonstrate robust control with balanced tuning.

Table 1: Performance Comparison of Different Scenarios

Scenario	K_p	K_i	K_d	**Response**	**Key Feature**
Without IMC	29	2	2	Sharp initial spike	Fast settling
With IMC	29	2	2	Smooth approach	Minimal overshoot
Concentration	18	0.5	10	Stable recovery	High derivative
Flow Rate	17	0.5	11	Controlled response	Damping optimized
Combined	24	0.5	4	Robust handling	Balanced tuning

3.1 Key Observations

Baseline (Without/With IMC): The baseline parameters $K_p = 29$, $K_i = 2$, $K_d = 2$ provide excellent setpoint tracking. The IMC (Internal Model Control) configuration offers superior performance with smooth approach and virtually no overshoot, demonstrating the benefit of model-based control strategies.

Concentration Disturbance: When inlet concentration changes (orange step), reduced proportional gain ($K_p = 18$) with significantly increased derivative action ($K_d = 10$) effectively dampens oscillations. Lower integral gain ($K_i = 0.5$) prevents integral windup during disturbances.

Flow Rate Disturbance: The 400% flow increase creates severe challenge requiring $K_p = 17$ and $K_d = 11$. The high derivative gain is crucial for anticipating rapid changes and maintaining stability during flow transients.

Combined Disturbances: The most realistic scenario uses $K_p = 24$, $K_i = 0.5$, $K_d = 4$ to handle both concentration and flow disturbances. This represents a compromise tuning that maintains robustness across multiple disturbance types while avoiding excessive controller action.

4 CONCLUSION

This project successfully demonstrated PID controller tuning for pH neutralization under various scenarios. The Ziegler-Nichols method provided reliable initial estimates ($K_p = 29$, $K_i = 2$, $K_d = 2$) which were adapted for specific disturbance conditions. Key findings include: IMC implementation significantly improves baseline performance with smoother response; concentration disturbances require high derivative action ($K_d = 10 - 11$) for effective damping; flow rate disturbances benefit from moderate proportional gain with strong derivative control; combined disturbances need balanced tuning for robust multi-disturbance rejection. The transport delay and measurement noise added realistic challenges. Future work could explore adaptive tuning strategies or model predictive control for enhanced performance under rapidly changing conditions.