Proceedings of the 8th International Conference of Recent Trends in Environmental Science and Engineering (RTESE 2024)
Chestnut Conference Centre - University of Toronto, Toronto, Canada – June 13 - 15, 2024
Paper No. 143
DOI: 10.11159/rtese24.143

Decoupled PID Controller Design for Multi-Input Multi-Output PVA Degradation Process in a UV/H_2O_2 Photoreactor

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Extended Abstract

Synthetic water-soluble polymers, exemplified by polyvinyl alcohol (PVA), are widely consumed in diverse industries as raw materials or process-facilitating agents such as coatings, solvents, or lubricants [1,2]. However, a substantial portion of these materials ends up in industrial wastewater, resulting in significant challenges in wastewater treatment. The non-biodegradable nature of these polymers necessitates employing advanced treatment processes, such as advanced oxidation processes (AOPs), to remove them effectively [3]. Among AOPs, the UV/H_2O_2 process has emerged as a promising solution for PVA degradation due to its proven efficiency in experimental studies [4–8]. Nonetheless, continuously achieving optimal PVA degradation while ensuring safe residual H_2O_2 levels in the process effluent remains a critical concern [9–11].

This study focuses on designing a robust multi-loop proportional-integral-derivative (PID) feedback control specifically tailored for the multi-input multi-output (MIMO) PVA degradation process in a UV/H_2O_2 photoreactor. This approach is selected due to the prevalence, adaptability, and simplicity of implementing PID controllers in industries, including wastewater treatment plants [12]. However, it is crucial to acknowledge that transitioning PID feedback control from a single-input single-output (SISO) system to a MIMO configuration introduces complexities that require meticulous consideration of process interactions.

The significant hurdles in formulating a multi-loop PID feedback control for MIMO systems encompass identifying the interactions among process variables, mitigating these interactions, and selecting optimal manipulated variable/control variable (MV/CV) control pairs [13,14]. Relative gain array (RGA) analysis is a valuable tool for navigating these challenges. One effective strategy to address process interactions involves implementing feedforward decouplers, enabling independent control of each CV by manipulating only one MV [15].

In this study, the implementation of RGA analysis facilitated the identification of interactions between key process CVs, including the effluent total organic carbon (TOC) and residual H_2O_2 concentrations (mg/L), and MVs including PVA feed flow rate (mL/min) and inlet H_2O_2 concentration (mg/L). Feedforward PID controllers, acting as decouplers, were designed and integrated into the closed-loop control system of the process to mitigate the indicated interactions.

Subsequently, PID controllers for each decoupled loop were meticulously tuned to ensure effective disturbance rejection on the CV within a closed feedback loop. The tuned controllers can also effectively manipulate the corresponding MV to track the desired setpoint trajectory. Tuning of PID parameters and rigorous simulation studies were conducted using MATLAB Simulink to validate the efficacy of the proposed control strategy. Simulation outcomes underscored the effectiveness of the designed control system, showcasing rapid response and settling times, stability, and minimal overshoot.

Furthermore, the practical applicability of the designed control system was examined through realizability analysis assessments of the designed decouplers. The nature of the lag compensator of the designed decouplers serves as evidence of their realizability and feasibility for implementation in real-world applications.

Overall, this study and its simulation results demonstrate the effectiveness of the proposed control strategy for PVA degradation in a UV/H_2O_2 photoreactor.

Keywords: water-soluble polymers; PVA degradation; UV/H_2O_2 process; wastewater treatment; multi-loop PID control; RGA analysis; controller design; decoupler design

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