Multi-Agent Reinforcement Learning Control of a Nonlinear Chemical Reactor

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ABSTRACT

Nonlinear chemical reactors are among the most challenging systems to control due to pronounced nonlinearities, coupled mass and energy balances, and strict operational constraints. Classical control methods often struggle with such systems. The van de Vusse reaction is a standard benchmark that demonstrates complex behavior, including multiple steady states and high sensitivity to operating conditions (Sánchez-Sánchez et al., 2026). Recent AI advances enable more adaptive, autonomous control of nonlinear processes (Szatmári et al, 2025).

Multi-agent reinforcement learning (MARL) marks a significant advance in AI for controlling complex, dynamic systems by coordinating multiple agents. Recently, MARL has attracted attention in chemical engineering for improving process control, optimizing performance, and enhancing chemical production efficiency (Ning and Xie, 2024).

This work presents a control architecture for a non-isothermal CSTR with van de Vusse kinetics. The system integrates a reinforcement learning agent for dynamic control, an anomaly detection agent for process monitoring, and a supervisory agent for real-time optimization. The simulation environment uses a dynamic reactor model with mass and energy balances. The control agent optimizes feed flow and heat removal to maximize intermediate product yield while ensuring thermal stability.

The proposed approach is evaluated against PI and MPC controllers under scenarios such as normal operation, feed and temperature disturbances, and uncertain kinetics. Simulations show the multi-agent system enhances disturbance rejection, improves target yield, and sustains safe reactor operation. The multi-agent approach demonstrates the potential of reinforcement learning with monitoring agents as a flexible, scalable framework for advanced nonlinear process control. This architecture may support future developments in autonomous process operation.

Keywords: Multi-Agent Systems, Reinforcement Learning, Process Control, Nonlinear Chemical Reactors, van de Vusse Reactor.

Acknowledgements: This work received financial support from Petrobras through cooperation agreement No. FEQUI.PETRO.0009, for which the authors express their recognition and gratitude for the support provided.

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