

Multi-Objective Quantum Optimization of Process Intensification Strategies

in Next-Generation Chemical Plants

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Abstract—The integration of quantum optimization techniques into chemical engineering has emerged as a frontier in achieving more efficient, sustainable, and adaptive process design. This study presents a qualitative investigation into the role of multi-objective quantum optimization frameworks for enhancing process intensification in next-generation chemical plants. The research explores how quantum-inspired algorithms—leveraging quantum superposition, entanglement, and probabilistic search mechanisms—can optimize multiple competing objectives such as energy consumption, production throughput, and environmental impact simultaneously. Through a comprehensive review of both academic and industrial literature, the study identifies key trends in the use of hybrid quantum–classical models for solving high-dimensional optimization problems in chemical plant design and operation. It examines how quantum-assisted methods, including the Quantum Approximate Optimization Algorithm (QAOA) and Variational Quantum Eigensolver (VQE), can accelerate simulation convergence and decision-making in process systems engineering. The qualitative findings underscore the transformative potential of quantum-enhanced computation in enabling process intensification, where chemical operations are redesigned for maximum efficiency and minimal ecological footprint. Furthermore, this research analyzes the interdisciplinary interface between quantum computing, chemical engineering, and sustainable manufacturing, emphasizing how algorithmic innovation can support cleaner, more resource-efficient production ecosystems. Conceptual models were developed to illustrate the role of quantum optimization in guiding strategic decisions related to resource allocation, system design, and environmental trade-offs. The study concludes that quantum optimization will likely become a cornerstone of the digital and sustainable transformation of the chemical industry, facilitating intelligent automation and data-driven sustainability in the decades ahead.

■ The global chemical industry is undergoing a paradigm shift toward sustainable process intensification, a design philosophy that aims to make chemical production systems more efficient, compact, and environmentally responsible [4]. Traditional

optimization approaches—based on deterministic and heuristic algorithms—have contributed significantly to process improvement, yet they often face limitations when confronted with the nonlinear, multi-objective, and high-dimensional nature of modern chemical plant operations [7]. Balancing factors such as energy efficiency, throughput, and environmental compliance demands advanced computational techniques capable of exploring vast and complex design spaces beyond

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