European Cryogenics Days & Cryogenic Heat and Mass Transfer Workshop 2025

Contribution ID: **2** Type: **Poster**

Quantum Machine Learning for Enhancing Cryogenic Fluid Simulations through Quantum Physics-Inspired Models

Wednesday 29 October 2025 14:00 (1 minute)

Abstract

Quantum Machine Learning (QML) is increasingly vital for modeling and optimizing cryogenic systems, particularly those involving liquid hydrogen in aviation, quantum technologies, and large-scale scientific experiments \[1,5,7]. By leveraging quantum physics-informed AI—such as Physics-Informed Neural Networks (PINNs) and Geometry-Aware Operator Transformers (GAOTs)—QML enables accurate simulation of low-temperature heat and mass transfer processes, critical for cryocooler design, storage, and transport systems \[5].

In aerospace, QML enhances predictions of thermofluidic behavior under extreme cryogenic conditions, improving safety, efficiency, and anomaly detection in hydrogen-based propulsion and storage systems \[5,8]. These models also optimize mesh generation and turbulence modeling in computational fluid dynamics (CFD), reducing computational costs while increasing predictive accuracy.

Cryogenics underpins quantum computing, where maintaining coherence in superconducting qubits requires precise thermal control. QML assists in simulating quantum dynamics and optimizing cryostat performance and error mitigation strategies \[2,6,7].

In large-scale scientific infrastructures, including high-energy physics and quantum experiments, QML accelerates materials discovery and infrastructure design by solving complex optimization problems \[1,3,4]. The intersection of QML and cryogenics is thus driving advances in simulation fidelity, thermal management, and cross-domain innovation.

References

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Author: SESHADITYA, a (quasi ai)

Presenter: SESHADITYA, a (quasi ai)

Session Classification: Poster session

Track Classification: Cryogenics for Quantum Technologies