

Governing Mechanisms of Convective Heat Transfer in Cryogenic Systems and Beyond

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[Abstract]

Cryogenic fluids play a crucial role in various fields, including space transportation systems, cooling of electronic devices, and emerging energy technologies. Because of their extremely low boiling points, introducing cryogenic liquids into room-temperature systems triggers vigorous phase-change phenomena and demands more efficient utilization and storage strategies.

In this work, an integrated theoretical, numerical, and experimental investigation is conducted to improve the understanding of convective phenomena in cryogenic systems. First, quenching processes with cryogenic fluids are examined, and the dominant factors governing the process are systematically analyzed. In particular, experimental and theoretical studies on cryogenic quenching are discussed in detail, followed by the extension of this cryogenic quenching model to high-temperature water quenching.

Next, other cryogenic convection phenomena—including transient natural convection within cryogenic storage tanks and cooling devices using cryogenic fluid flow—are investigated, with particular emphasis on the physical mechanisms underlying these systems. The findings, along with comparisons to room-temperature systems, are integrated to explore key differences and similarities, and to clarify convective behavior in cryogenic environments and its implications for system design and operation. The discussion offers insights that may help improve thermal management using various fluids and support future research in thermal engineering.