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SIMILARITY-BASED MODEL OF EXPERIMENTS FOR ANALYZING FREEZING AND MELTING IN HOT WATER DRILLED BOREHOLES

In hot-water ice drilling, the melting rate of the borehole wall during drilling operations and the freezing rate leading to borehole closure during standstill periods are critical parameters for evaluating drilling efficiency and operational safety. However, in-situ measurements of these parameters present significant challenges, including high costs, operational uncertainties and delay of data acquisition. This necessitates systematic laboratory experimentation under controlled conditions.

As an engineering application of heat transfer theory, hot water drilling technology can benefit from scaled model experiments - a well-established methodology widely employed in heat transfer research for aerospace (Ran et al. 2024, Lin et al. 2022), permafrost (Yang et al. 2025, Chen et al. 2022), metal casting (Ren et al. 2024) and some other fields (Jia et al. 2024, Yang et al. 2024). Such modeling approaches have demonstrated considerable advantages in reducing experimental costs while improving data reliability.

This study proposes a comprehensive theoretical design scheme for model experiments addressing phase-change phenomena in borehole walls induced by hot water drilling in polar regions. Through dimensional analysis with borehole diameter variation rate and water temperature of outlet of annulus between hose and borehole wall as dependent variables, along with key physical variables influencing the freezing and melting processes as independent variables, a series of similarity criteria were derived. These include temperature similarity criterion, geometric similarity criterion, time similarity criterion, and flow rate similarity criterion. Based on these similarity criteria, the core parameters for model experiments were determined according to capabilities and conditions of experimental equipment. The scaling ratios between actual engineering variables and model experimental parameters were established as follows: temperature similarity ratio 1:1, geometric similarity ratio 2:1, time similarity ratio 2:1, and flow rate similarity ratio 4:1.

This study innovatively designed a multifunctional experimental platform architecture, incorporating a high-temperature hot-water circulation system, low-temperature ice environment simulation chamber, temperature measurement system, and visual borehole diameter measurement apparatus. This theoretical design scheme establishes a foundation for subsequent physical simulation experiments of phase-change processes in hot water drilled boreholes and provides significant guidance for the scientific optimization of process parameters in polar hot water drilling operations.

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