Poster Session

9th International Symposium on Ice Drilling Technology

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

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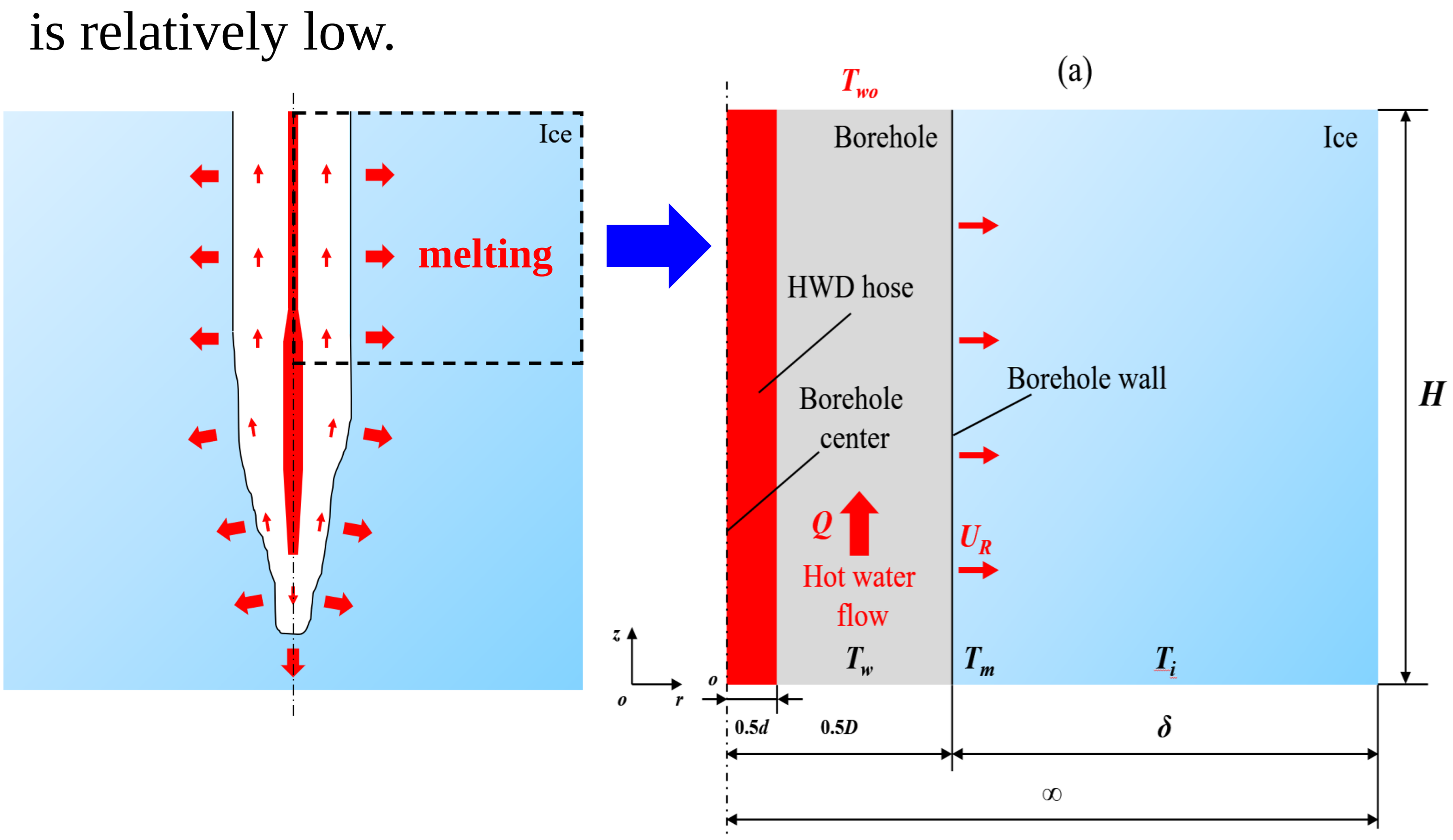
Introduction

The borehole diameter change rate is of great engineering guidance for hot water drilling(HWD) projects. However, real-time measurement of this rate is difficult in practical engineering, requiring experimental studies to derive general laws. Similarity experiments based on similarity theory, proven reliable across industries, well reflect real operating conditions. In this study, we developed a HWD similarity model through similarity theory, deducing similarity criteria with parameters including time, hot water flow rate, hot water temperature, ice temperature, initial borehole diameter, and hot water(HW) drill hose outer diameter, etc. Our goal is to derive similarity experimental parameters using these criteria based on engineering drilling parameters, offering a new, and reliable method to study the borehole diameter change law in HWD projects.

Similarity criterion | Hot water drilling | Design of experiment

Method

A modeling approach using cylindrical coordinates is adopted for the ice melting process of the HWD process. The selected modeling domain is located above the nozzle of the HW drill, where the borehole exhibits a standard annular cylindrical shape. Within this domain, the fluid flow velocity is relatively low.



The rate of borehole melting by hot water is a complex multi-factor function, experimental research on it is challenging. Furthermore, the hot water ice-melting process satisfies the three fundamental equations of fluid mechanics that incorporate the latent heat of fusion. Through analysis, we can integrate the parameters of the dominant factors influencing the hot water ice-melting process into this borehole melting rate function U_R, which is expressed as the following formula:

$$U_R = f(Q, \rho_w, t, T_{wi}, T_i, D, d, q_i, k_w, k_i) \quad (1)$$

in which, Q is HW flow rate, L/min,

ρ_w is HW density, kg/m^3,

t is time, s,

T_{wi} is HW temperature at inlet, °C,

T_i is ice temperature , °C,

D is initial borehole diameter, mm,

d is hose outer diameter, mm,

q_i is latent heat of ice, 334.3 kJ/kg,

k_w is heat transfer coefficient of HW, W/(m·°C),

k_i is heat transfer coefficient of ice, W/(m·°C).

By selecting time as n_1, HW temperature at inlet as n_2, HW density as n_3, and initial borehole diameter of as n_4 which are the fundamental physical quantities, we can unify other physical quantities into the following formulas based on the Buckingham π Theorem.

$$\begin{cases} N = \pi n_1^x n_2^y n_3^z n_4^a \\ n_i = \pi_i n_1^{x_i} n_2^{y_i} n_3^{z_i} n_4^{a_i} \end{cases} \quad (2)$$

in which, N is dependent variable U_R,

n_i is other independent variables,

π and π_i, are the respective corresponding similarity criteria, dimensionless,

x and x_i ,y and y_i, z and z_i, a and a_i are exponents.

Solving this system of expressions, similarity criteria corresponding to the problem under this study can be obtained as follows from π_1 to π_8.

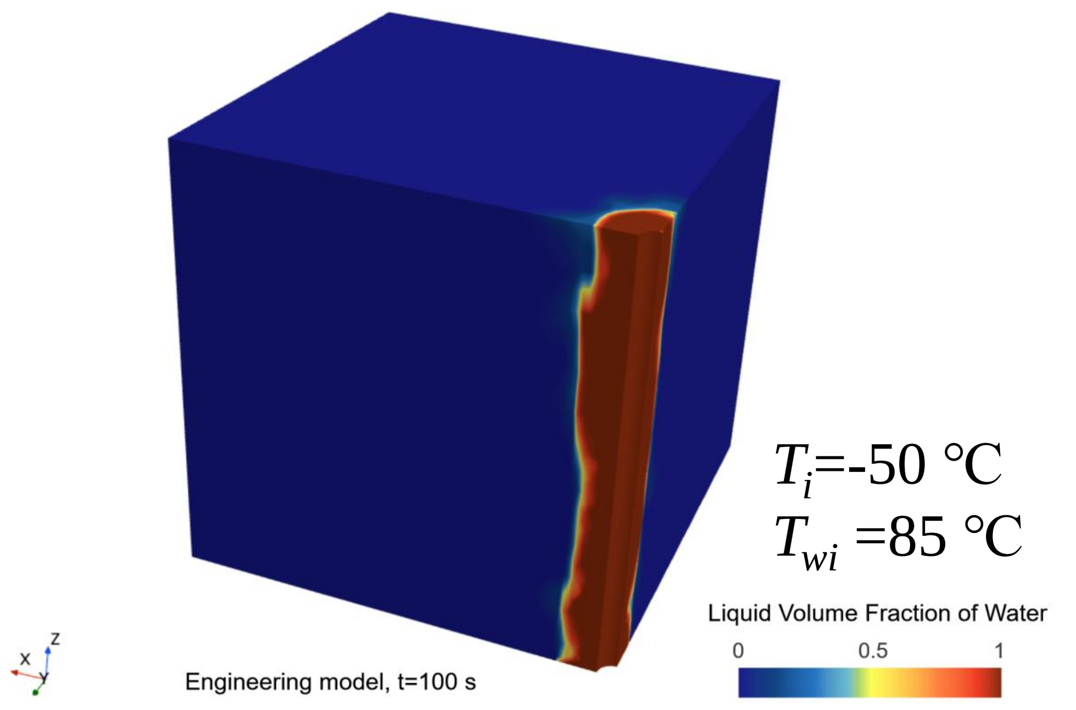
Method

$$\begin{cases} \pi_1 = \dfrac{T_{wo}}{T_{wi}} \\ \pi_2 = \dfrac{U_R t}{D} \\ \pi_3 = \dfrac{Qt}{D^3} \\ \pi_4 = \dfrac{T_i}{T_{wi}} \\ \pi_5 = \dfrac{d}{D} \\ \pi_6 = \dfrac{L_f t^2}{D^2} \\ \pi_7 = \dfrac{k_w t^3 T_{wi}}{\rho_w D^4} \\ \pi_8 = \dfrac{k_i t^3 T_{wi}}{\rho_w D^4} \end{cases} \quad (3)$$

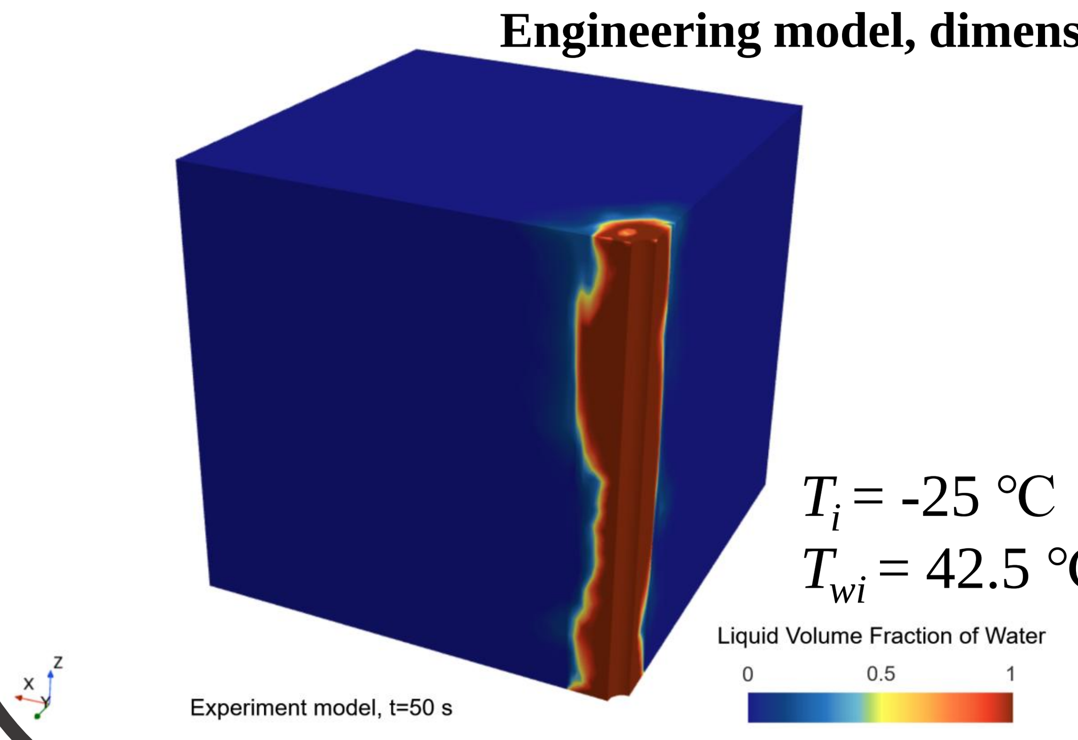
The derived similarity criteria are used to design the experimental parameters required for similarity experiments. The corresponding relationships between similarity experimental parameters and the parameters used in engineering applications are shown in the table below.

Variables	Engineering	Experiment	Ratio
Q	210 L/min	52 L/min	**4:1**
T_{wi}	85 ℃	42.5 ℃	**2:1**
T_i	-50 ℃	-25℃	**2:1**
D	250 mm	125 mm	**2:1**
d	68 mm	34 mm	**2:1**
t	300 s	150 s	**2:1**

The ratio design derived above was validated by numerical simulation method, and the resulting simulated cloud maps of liquid phase distribution is shown as follows.



Engineering model, dimensionless time t*=0.33



Experiment model, dimensionless time t*=0.33

Conclusions

In this study, the similarity principle and the derivation of similarity criteria are innovatively incorporated into the design of HWD experiments. A series of similarity criteria involving the melting phenomenon are established, and a specific experimental parameter design is proposed. By utilizing numerical simulation method, the feasibility of this model is verified. The results indicate that under the condition of identical dimensionless time, the melting phenomena of the engineering model and the experimental model are highly consistent.

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