Spallation Drilling for Deep Heat Mining

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Overview

Spallation Drilling

Previous Work: SCWO

Ideas for New Project
Deep Heat Mining

Spallation Drilling

Conventional drilling

Spallation Drilling

Flame jet spallation

Holes spalled by a pulsed Laser

Zhiyue Xu et al. (2004)
Spallation Drilling

„Thermal Fragmentation“ is used in Russia:

Surface mining:
Narrow vein ore extraction

Thermal drilling device
Spallation Drilling: Costs

US Patent, Potter et al., 1998
Spallation Drilling: Principle

US Patent, Potter et al., 1998
Spallation Drilling: Theoretical Approach

Flame

Rock

T

x
Spallation Drilling: Theoretical Approach

\[ \Delta T_s = T_s - T_0 \]

rock temperature change at spallation
Spallation Drilling: Theoretical Approach

1. A very simple approach for $\Delta T_S$ (Gray, 1965)

$$\Delta T_s = T_s - T_0$$

rock temperature change at spallation

mechanical rock properties:
$E$, $\nu$, $\beta$, $\sigma_c$

$$\Delta T_s = \frac{(1-\nu) \cdot \sigma_c}{\beta \cdot E}$$
Spallation Drilling: Theoretical Approach

2. A more elaborate approach for $\Delta T_s$ (Rauenzahn and Tester, 1989)

Temperature profile:

$$T \sim \Delta T_s \cdot \exp(-u \cdot x / a) + T_{r0}$$

Heat flux at surface:

$$\dot{q} = -\lambda \frac{dT}{dx} \bigg|_{x=0} = \rho \cdot c_p \cdot u \cdot \Delta T_s$$

Compressive stress load:

$$\sigma_s = \frac{\beta \cdot E \cdot \Delta T_s}{(1-\nu)}$$

Weibull distribution (theory of failure):

$$G \sim 1 - \exp \left[ -\int_0^V \left( \frac{\sigma}{\sigma_m} \right)^m \, dV \right] = 0.5$$

median condition
Spallation Drilling: Theoretical Approach

2. A more elaborate approach for $\Delta T_S$ (Rauenzahn and Tester, 1989)

$$\Delta T_S = \left[ \left( \frac{\dot{q}}{\rho \cdot c_p} \right)^3 \cdot \left( \frac{(1-\nu) \cdot \sigma_0}{\beta \cdot E} \right)^m \cdot \left( \frac{2 \cdot \phi \cdot 693}{\pi \cdot C_L^2} \right) \cdot \left( \frac{m}{a_r} \right)^3 \right]^{m+3}$$

$\dot{q}$ Heat flux to plate

$\sigma_0, m$ Weibull parameters

$\Delta T_s = T_s - T_0$

rock temperature change at spallation
Link to LTR

Supercritical conditions downhole

\[ H > 2.3 \text{ km} \]

\[ p > 221 \text{ bar} \]

Our SCWO-reactor

\[ T_{\text{flame}} \approx 1200 \text{ C} \]

\[ p = 250 \text{ bar} \]
SCWO

Autoignition of flame
Project Ideas I

Situation downhole

- nozzle
- conditions (p,T)
- free jet

Modifications on reactor

- Fuel stream
- Oxygen
- Inner cooling water stream
- Outer cooling water stream (in)
- Outer cooling water stream (out)
- Reactor effluent
Project Ideas II

\[ \Delta T_S = \left( \frac{\dot{q}}{\rho \cdot c_p} \right)^3 \cdot \left( \frac{(1 - \nu) \cdot \sigma_o}{\beta \cdot E} \right)^m \cdot \left( \frac{2 \cdot 0.693}{\pi \cdot C_L^2} \right)^3 \cdot \left( \frac{m}{a_r} \right)^3 \]
Project Ideas II

Insertion of a flat plate:

\[ \Delta T_S = \left[ \frac{\dot{q}}{\rho \cdot c_p} \right]^3 \cdot \left( \frac{1 - \nu}{\beta \cdot E} \right)^m \cdot \left( \frac{2 \cdot 0.693}{\pi \cdot C_L^2} \right) \cdot \left( \frac{m}{a_r} \right)^3 \]

\(
\rightarrow \text{prediction of spall thickness}
\)

Heat flux sensors:
- Heat flux
- Surface temperature
Project Ideas II

Impinging flame jets – Heat transfer mechanisms

1. Convective heat transfer
2. Thermochemical heat release (TCHR)
3. Radiative heat transfer
4. Condensation

Research goals:

- Comparison of experimental results:
  → Heat Transfer Enhancement/Deterioration
  → Estimation of heat radiation
- Simplified model of overall heat transfer
Project Ideas III

Ignition of Flame (Autoignition)

Stability of Flame
  - Blowoff-Experiments
  - Flashback-Experiments

Process Design

Realistic operation conditions $p, T$
Thanks for your attention!