Drilling Technology Development for Supercritical Geothermal Resources in Japan

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Shigemi Naganawa
Frontier Research Center for Energy and Resources
The University of Tokyo
Tera-Watt Energy from Supercritical Geothermal Resources in Japan Island Arc

- A comprehensive feasibility study on supercritical geothermal resource development in Tohoku, the Northern part of Japan was just finished

- One of the leading projects on new technology for energy and environment supported by the New Energy and Industrial Technology Development Organization (NEDO)

- Aiming to construct a supercritical geothermal demonstration power plant in early 2030s

- Principal Investigators:
  - National Institute of Advanced Industrial Science and Technology (AIST)
  - Tohoku University (Prof. Tsuchiya)
  - Geothermal Engineering Co., Ltd (GeoE)
  - Fuji Electric Co., Ltd.

Asanuma et al. (2012)
Needs for Extremely High Temperature Drilling Technology

- Drilling is a key technology for success in future supercritical geothermal power generation
- Development of effective drilling and completion technology for **deep ductile formation over 500°C**
  - Vertical Depth: 5–6 km (proven in oilwell drilling)
  - Formation Pressure: 30–50 MPa (proven in oilwell drilling)

![Diagram showing static reservoir pressure and temperature conditions for different geothermal categories](image-url)
Experience in Kakkonda WD-1a Drilling

Fig. 1 Location and geothermal cross-section of the Kakkonda field.

Kasai et al. (2000)
Experience in Kakkonda WD-1a Drilling

- In a geothermal exploration well "Kakkonda WD-1a" drilled in 1995, formation temperature was over 500°C
- The overall temperature limitations remain below typical geothermal development conditions
- **Downhole cooling** successfully cooled and maintained downhole temperature below 170°C
- This was achieved by using Top Drive System, continuous mud circulation, high-temperature mud and closed-type surface mud cooler

Source: http://www.drillcool.com

Source: Website of GeoE
Temperature Limitation of Downhole Tools and Materials

- Although there are some tools available for use in HT over 200°C, temperature limitation for tools using elastomer components is still approximately 175°C.

- Downhole cooling is still an essential drilling operation.
Low Rate of Penetration is another Problem

- PDC bit have more than 75% of market share in Oil & Gas

**Advantage:** Higher ROP, long bit life and high heat resistance because of lack of elastomer-seal rolling components

**Disadvantage:** Expensive, poor performance when drilling hard and abrasive, or cohesive formations in geothermal fields

- Roller-cone bits are still a standard for geothermal drilling

- **Breakthrough in drilling technology is needed**
Unconventional Non-mechanical Drill Bit

New drilling system unnecessary of special electronics and with minimum mechanical moving parts: more advantageous than other novel drilling concepts

Highly reliable and robust system under harsh and hostile environment

Reduction of down Time or non-productive time (NPT) = Effective cost reduction
Novel Drilling proposed in the 1960s

- Novel drilling systems were never implemented so far

Melting and Vaporization

- Atomic
- Fusion
- Electric Arc
- Plasma
- Electron Beam
- Laser

Thermal Spalling

- Jet Piercing
- Forced Flame
- Electric Disintegration
- High-Frequency Electric
- Induction
- Microwave

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Maurer (1966)
Innovative Drilling Technology Development
(2-Year Project, 2015–2017)

- **Thermal-Shock Drilling System**
  - Taking a best advantage of thermal stress or thermal shock generated in formation rock induced by rapid bottomhole cooling, although extremely high temperature is the most critical problem for drilling tools
  - Principal Investigators:
    - The University of Tokyo, Tohoku U., AIST, GeoE, Geothermal Energy Research & Development Co., Ltd. (GERD), Teiseki Drilling Co., Ltd.

- **Laser Drilling System**
  - Fundamental study was finished as a JOGMEC project
  - CO$_2$ laser instead of fiber laser
  - Principal Investigators:
    - Japan Drilling Co., Ltd. (JDC), Telnite Co., Ltd., Tohoku U., Osaka U.
Conceptual Proposal of Decompression Drilling by Tohoku University Group

Drilling

Baby hole drilling (naming by Prof. Ito)

Bumping/Low-temp fluid Injection tool setting

Rapid decompression and boiling

Chilled water injection and boiling

Fracture Cloud
Decompression/Boiling/Cooling induced Thermal-Shock Drilling

- A leading research project on development of innovative drilling technology by use of thermal-shock or thermal-stress failure of rock rapidly cooled by decompression and boiling of the drilling fluid bottomhole
  - If decompression or depressurization of drilling fluid is controlled at the surface, the system can be effective under high temperature hostile environment because of unnecessity of complex mechanical action in downhole tools
  - As it is almost no contact with bottomhole, the bit wear would be very small resulting in reduction of operation time and drilling cost

- Implementation of downhole cooling system
- Experimental work on rock failure mechanism
1. Hydrothermal Rock Failure Experiments in Tohoku University

- Based on geological and mechanical insights from naturally observed thermal-stress failure of formation rock
- Thermal-stress failure experiments of quartz specimen under decompression and boiling
- Rock failure experiments using simulated borehole
  - Brittleness in granite specimen was observed
2. Wellbore Temperature Simulation applicable to Supercritical Condition

- Wellbore temperature simulation technology applicable to supercritical condition is needed to controlling decompression/boiling/rapid-cooling bottomhole.
- Supercritical calculation module will be developed and complied in existing code such as "GEOTEMP2".

![Graphs showing temperature profiles](image)

Wooley (1980)

![Graph showing temperature profile](image)

$T_{\text{crit}}$ = 374°C (705°F)

Fig. 10 – API study of Gulf well – fluid temperature profile after 30 minutes.

Fig. 11 – API study of Gulf well – fluid temperature profile after 3 hours.
3. Development of "Heat Expansion Packer"

- The packer subjected to **expand only by heat expansion of the fluid** confined in the packer element
- High heat resistant because the packer would have **no sealing element**
- Large expansion and/or downsizing can be possible depending on selection of confined fluids
- Small size prototype packers are now tested in lab

**"Thermal Expansion Packer" Concept**

Patent Pending (Shimada et al. 2015)
4. Acid- and Corrosion-Resistant Materials under Supercritical Environment

- **Acid- and corrosion-resistant materials** subjected to be exposed to repeated heat and pressure reductions
- Conventional OCTGs and geothermal cement with silica are insufficient for long-term well integrity

**CO₂ Partial Pressure (atm)**

- **Sweet**: 0.2-0.5
- **Sour**: 0.0035-0.05–0.1

**H₂S Partial Pressure (atm)**

- **API Normal Grade**
  - High Cr Stainless Steel
    - 9Cr Steel (−100°C)
    - 13Cr Steel (−150°C)
    - Two-Phase Stainless Steel (22Cr, 25Cr)
- **API Low Strength Grade (−L80)**
  - Cr-Mo Steel (C90, T95)
- **Premium Cr-Mo Steel**

**Ni base Cr-Mo High Alloy**

- Conductor Casing
- Surface Casing
- Intermediate Casing
- Production Casing

http://www.Encana.com/
Underwater Granite Processing by CO₂ Laser

Irradiating pattern by CO₂ laser in water: Laser beam reciprocating while rotating

CO₂ Laser power: 11kW

Granite in water chamber

Generated particle

Max Depth 60mm

Max Depth 80mm

Diam. 75mm

Diam. 75mm

Elapsed Time
Summary

- Projects on supercritical geothermal system development is initiated in Japan supported by NEDO
  - Comprehensive feasibility study (just finished this year)
  - Development of Thermal-shock drilling system (–2017)
    - Rock failure mechanism and drilling system
    - Thermal expansion packer
    - Casing and cementing under supercritical condition
    - Thermal-hydraulic wellbore simulation technology
  - Development of Laser drilling system (–2017)
    - Exploration technology (2016?–)
    - Reservoir modeling and simulation (2016?–)
    - (2017?–)
- First experimental and exploratory is planned to be drilled within a few years