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MAGMA ENERGY OVERVIEW AND STATUS REPORT

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ABSTRACT

Up to 500,000 Quads of thermal energy are believed to be contained in crustal magma bodies within the U. S. at temperatures in excess of 600°C and at depths less than 10 km. Scientific feasibility of utilizing this energy resource was concluded after a seven-year study that culminated in successful energy extraction experiments in molten rock at Kilauea Iki lava lake. The current DOE program is developing technology to experimentally extract energy from a silicic magma body so that engineering feasibility of the magma energy concept can be evaluated. At this point, significant progress has been achieved in three areas: Geophysics and site selection, Energy Extraction Processes, and Geochemistry/-Materials. Future activities will be focused by drilling and evaluating a deep exploratory well in Long Valley caldera where active magma is expected.

THE DOE MAGMA ENERGY EXTRACTION PROGRAM

What is the Magma Energy Program?

A project to evaluate the engineering feasibility of extracting energy directly from crustal magma bodies.

How big is the resource?

50,000 to 500,000 Quads in partially molten state estimated for the U.S. within 10 km of the surface. (U.S. total energy usage: 75 Quads/yr)

Who is involved?

Funding agency:	DOE Geothermal Technology Division
Implementation:	Sandia National Laboratories
Other Participants:	National Laboratories, U.S. Geological Survey, and several Universities

Can it be done?

Technology has been successfully demonstrated in a molten lava lake in Hawaii at temperatures in excess of 1,000°C.

What is the program goal?

To demonstrate feasibility of magma-generated power by the year 2000.

What is the next step?

Evaluate the resource in Long Valley caldera by drilling a 6 km deep exploratory well. Drilling will begin in the summer of 1989.

EVIDENCE SUPPORTING EXISTENCE OF SHALLOW MAGMA BODIES

- Abundance of granite bodies in the geologic record
- Large erupted volumes of silicic magma
- Extensive subsidence to form calderas

ENGINEERING FEASIBILITY OF MAGMA ENERGY

MAJOR QUESTIONS (with current approach)

- Accuracy of resource estimate (drill Long Valley exploratory well)
- Effectiveness of downhole heat exchanger (analysis, laboratory experiments, large-scale experiment, full-scale experiment in magma)
- Cost of drilling and well completion (technology development: insulated drill pipe, ceramic cements, jet drill bits; Long Valley exploratory well, Long Valley energy extraction well)
- Materials lifetime (magma characterization, compatibility experiments, geochemistry of circulating heat transfer fluids)

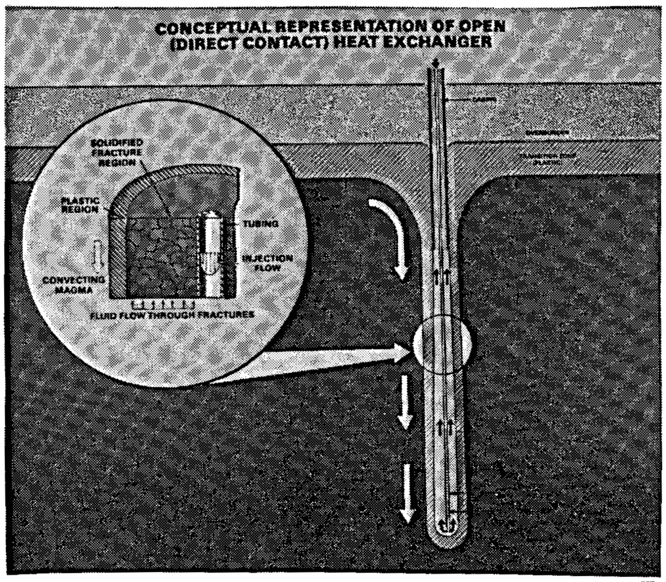
MAGMA ENERGY ORGANIZATION

LONG VALLEY OPERATIONS

- **Exploratory Well Drilling**
- **Supporting Science**

LABORATORY AND ENGINEERING SUPPORT

- **Drilling Techniques**
- **Energy Extraction**
- **Geochemistry and Materials**

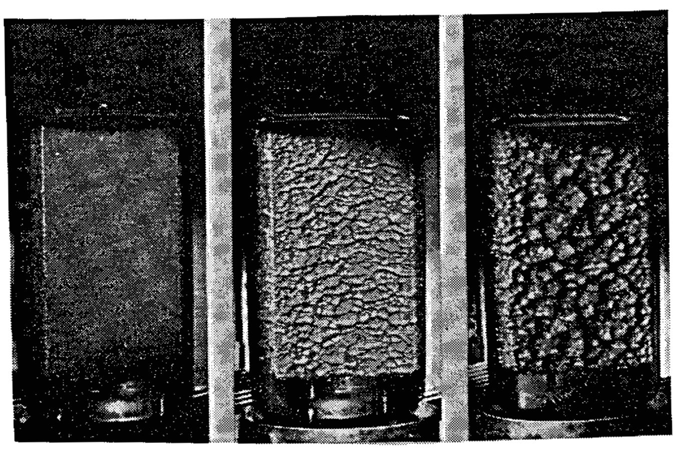


1. PHENOMENOLOGICAL STUDIES

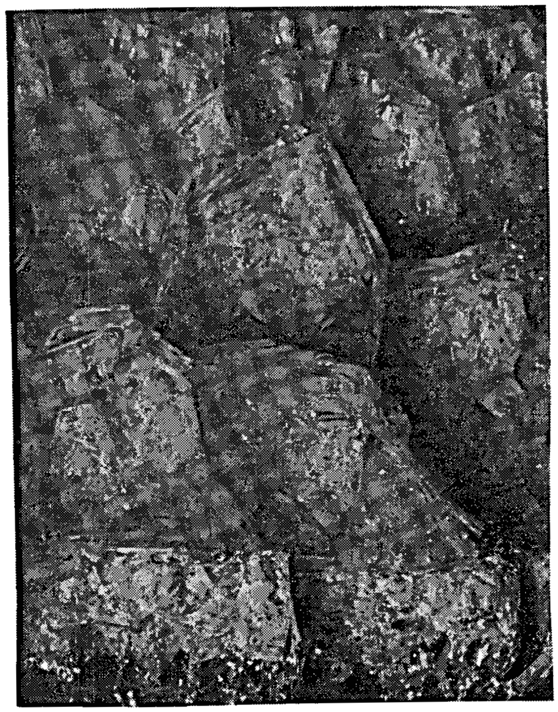
   Thermal Stress Fracturing
   Magma Chamber Convection
   Effect of Thermal Radiation
   Heat Transfer in Fractured/Porous Media
   Volcanic Hazard

2. NUMERICAL MODEL OF ENERGY EXTRACTION

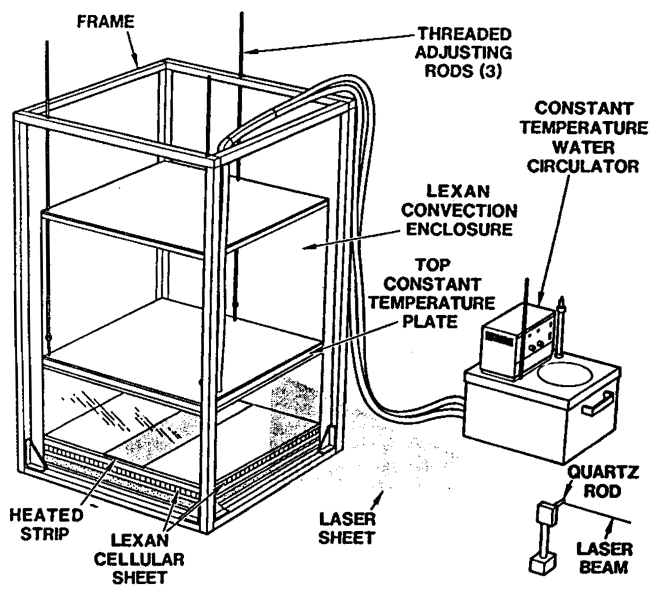
3. THERMODYNAMIC SYSTEM ANALYSIS



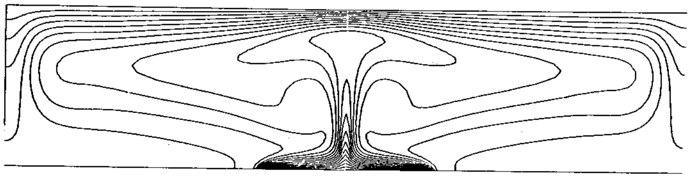
Thermal stress fracturing experiments show cell-like fracture development.



Close-up of cell-like structure.



Convection experiment to evaluate effects of large viscosity variation.



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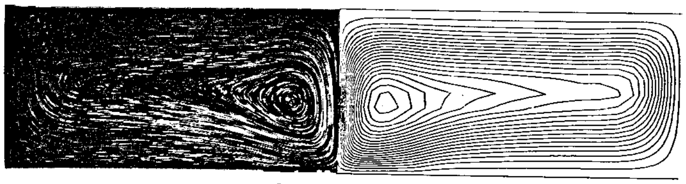
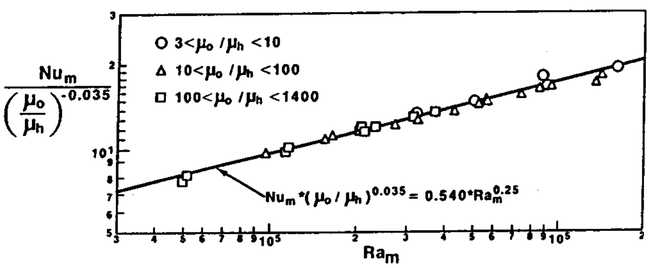


STREAMLINES

Measured and calculated data for convection with large viscosity variation.



Experimental correlation for convective heat transfer with large viscosity variation.

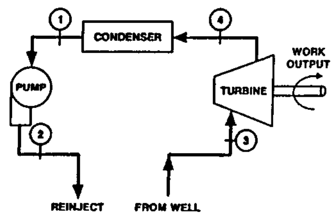
NUMERICAL SIMULATION-SINGLE WELL EXTRACTION

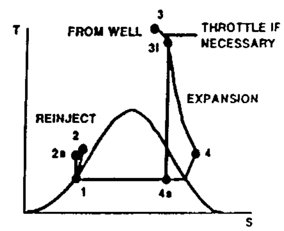
- GENERAL PURPOSE STEADY-STATE SIMULATION CODE COMPLETED
- PHYSICS INCLUDE
  - COMPRESSIBLE STEAM/WATER FLOW
  - PHASE CHANGE (FLASHING) EFFECTS
  - TWO PHASE CHOKING EFFECTS
  - FORMATION HEAT TRANSFER AND AREA CHANGE
  - OPEN OR CLOSED HEAT EXCHANGE CONFIGURATIONS
  - FLOW IN FRACTURED/POROUS MEDIUM IN OPEN EXCHANGER
  - IMPLICIT DETERMINATION OF SOLIDIFICATION BOUNDARY

THERMODYNAMIC SYSTEM ANALYSIS

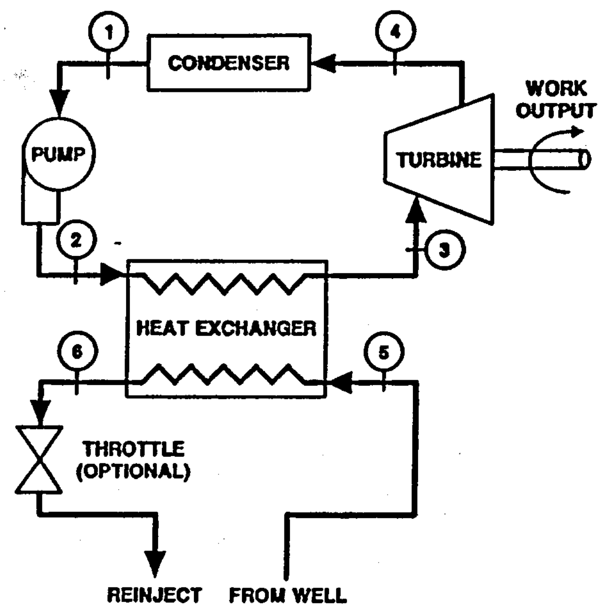
- OPEN RANKINE CYCLE
- CLOSED RANKINE CYCLE

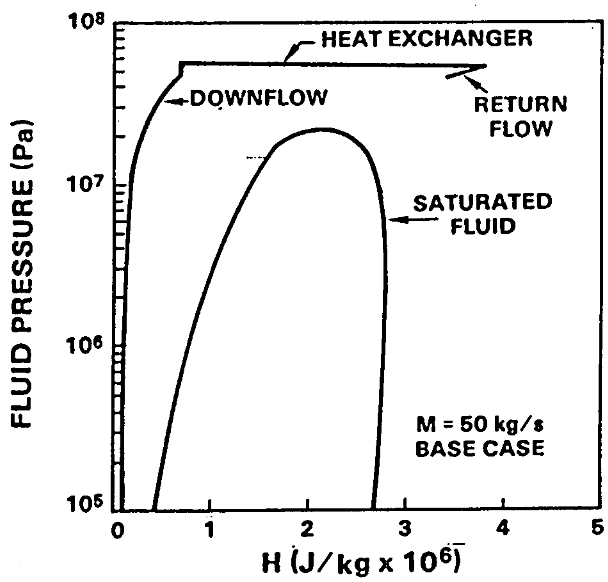
OPEN RANKINE CYCLE



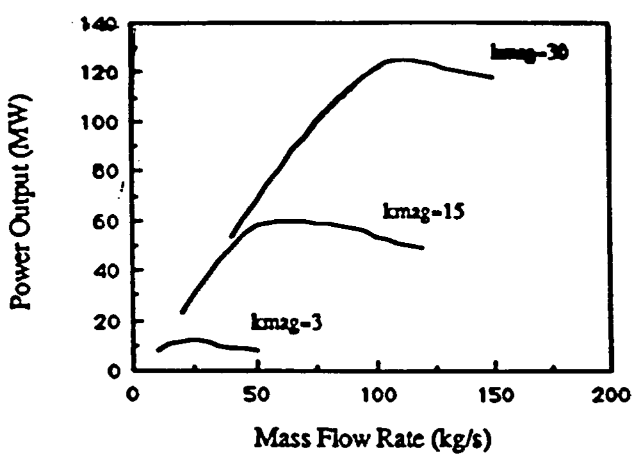


CLOSED RANKINE CYCLE





Analysis of magma energy extraction - fluid state points.



Power output for the closed cycle. Pinch point temperature difference is 8 degrees C, turbine efficiency is 80% and all results have a turbine exit quality of 90% or greater.

GEOCHEMISTRY AND MATERIALS

Objectives

- Chemical characterization of Inyo magma
- Metal compatibility studies with magma, glass, or fluid
- Mass transport phenomena in an open system heat exchanger
- Volcanic hazards related to decompression or cooling

Magma Characterization

Goal:
- Characterize the chemical composition of magmas at sites of interest for Magma Energy Extraction.

Approach:
- Chemically analyze lava flows for anhydrous composition, and volcanic gases, glassy volcanic ejecta and glass inclusions for dissolved volatiles.

Magma Characterization Summary

- Basaltic magmas erupt from deep reservoirs at very high temperatures (1200°C), and are characterized by high S and low (H20+Cl) contents, typical site is Hawaii.

- Rhyolitic magmas are found in large reservoirs at shallow depths (<8 km) and are characterized by high (H20+Cl) and low S contents at temperatures of 900°C, typical site is Long Valley, CA.

Material Compatibility

Goal:
- Evaluate the survivability of commercially available alloys for use as a heat exchanger material in a hydrous rhyolite magma.

Approach:
- Experimentally react commercial alloys with a volatile-bearing rhyolite magma (LOCA conditions - 850°C, 200 MPa), with a quenched rhyolite magma (hydrous glass - 500°C, 50 MPa), or with a hydrothermal fluid (500°C, 50 MPa). All tests are to be followed by chemical (SEM/EDS) examination of the metal surface/interface for signs of corrosion.

Materials Compatibility Summary

- Experimental procedures were developed for compatibility testing of commercial alloys in volatile-bearing rhyolite magma.

- Oxidation, not sulfidation, is the main corrosion problem for all alloys in a volatile-rich rhyolitic magma.

- Nickel-base superalloys, including commercially-available drillpipe, have very good corrosion resistance and strength in a rhyolite magmatic environment (850°C, 2000 bars).

- Reaction rates between alloys and silicates are significantly reduced at normal operation conditions (500°C, 500 bars).

- Hydrous rhyolite glass crystallizes at normal operating conditions (500°C, 500 bars) yielding anhydrous silicates and a vapor phase.

- Oxidation, not SCC or sulfidation, is the principal corrosion problem for nickel-base alloys in brines at elevated P & T (500°C, 500 bars).

<u>Mass Transport</u>

Goals:
- To predict silicate dissolution rates and solution composition in a direct contact heat exchanger system and to evaluate permeability changes from the dissolution of primary phases or precipitation of secondary phases.

Approach:
- Characterize silicate dissolution mechanisms in aqueous solutions at low and high temperatures (25-500°C).

- Measure silicate dissolution rates at high temperatures and pressures.

Feldspar Dissolution in Aqueous Solutions

Dissolution mechanism in acids at 25-45°C:
- hydrolysis of bridging si-O-Al bonds (rate controlling step)
- ion exchange of alkalies and alkaline earths with solution
- Eventual repolymerization of Si-rich hydrated layer

Rate of aluminosilicate dissolution:
- Affected by solution pH, temperature, and reaction time
- not affected by crystallographic orientation and defect density

Model predicts that dissolution rate:
- increases with increasing Al/Si ratio in tetrahedral sites
- Decreases when absorbates (e.g. Fe) react with silanol groups

Volcanic Hazards

Goal:
- To evaluate the likelihood of volcanic eruptions resulting from vapor exsolution during drilling (rapid decompression or energy extraction (slow cooling).

Approach:
- Measure rates of vapor exsolution during isothermal decompression of the volatile-saturated magma ($\Delta P/t$ = 1-100 MPa/min).

- Measure vesiculation rates during isobaric (150 MPa) crystallization of a hydrous rhyolitic magma ($\Delta T/t$ = 0.02 - 150°C/min).

Preliminary Results

- Incomplete degassing (50%) of oversaturated rhyolite magma during isothermal (850°C) decompression from 150⇒50 MPa.

- Anhydrous crystal growth (feldspar and quartz) during isobaric (150 MPa) cooling <25°C/hr. resulting in complete degassing of crystallized magma.

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