

Feasibility of Drilling with Compressed CO₂ for Autonomous Water Exploration on Mars

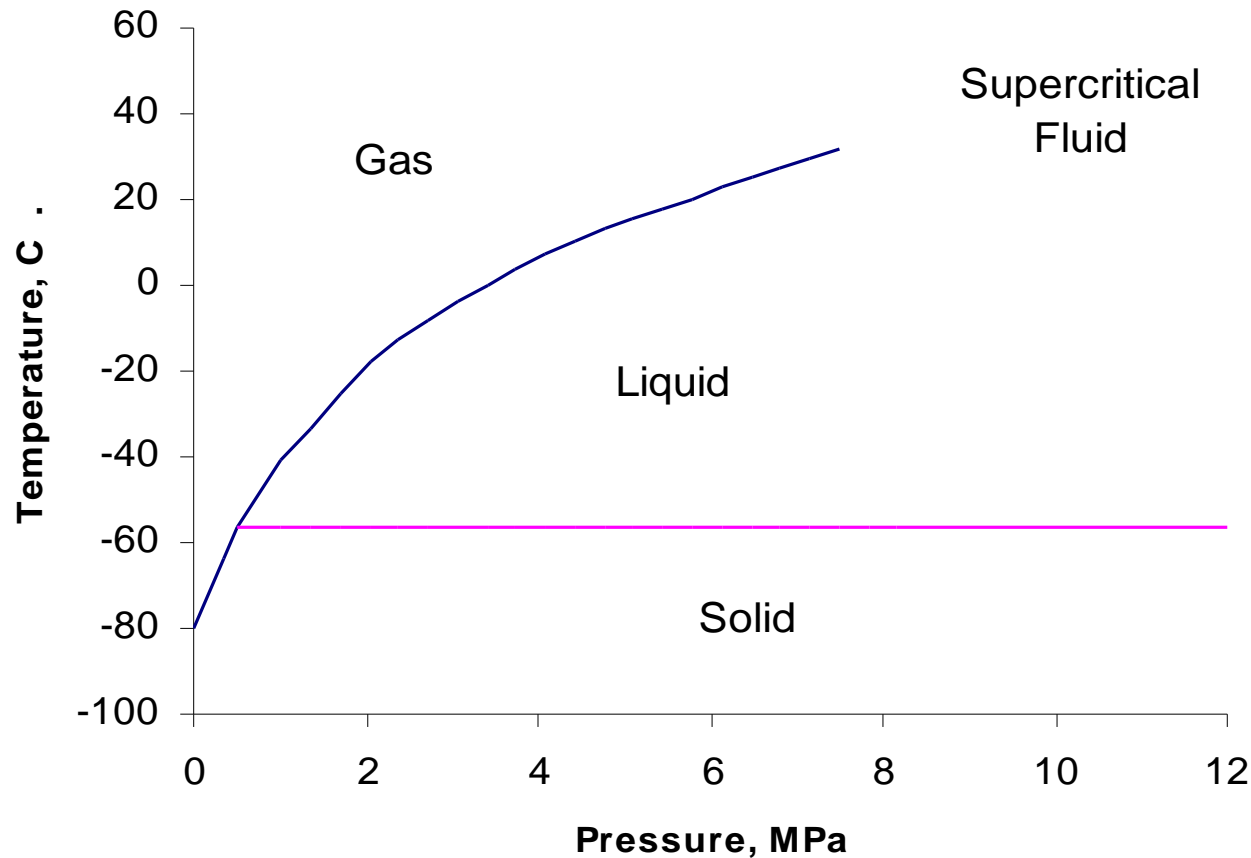
Jack Kollé

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Objective and Constraints

- ◆ Drill 1 km to Search for Liquid Water
 - Mixed formations: layered flood basalts, regolith, pyroclastics, sediment?
- ◆ Constraints
 - Unmanned, autonomous system
 - Low power, low mass and high reliability
 - Atmosphere: 6 mbar carbon dioxide at -40 °C
 - Gravity: 0.38 earth

Carbon Dioxide



Gas Properties

$$k = 1.288$$

$$\text{MWT} = 44$$

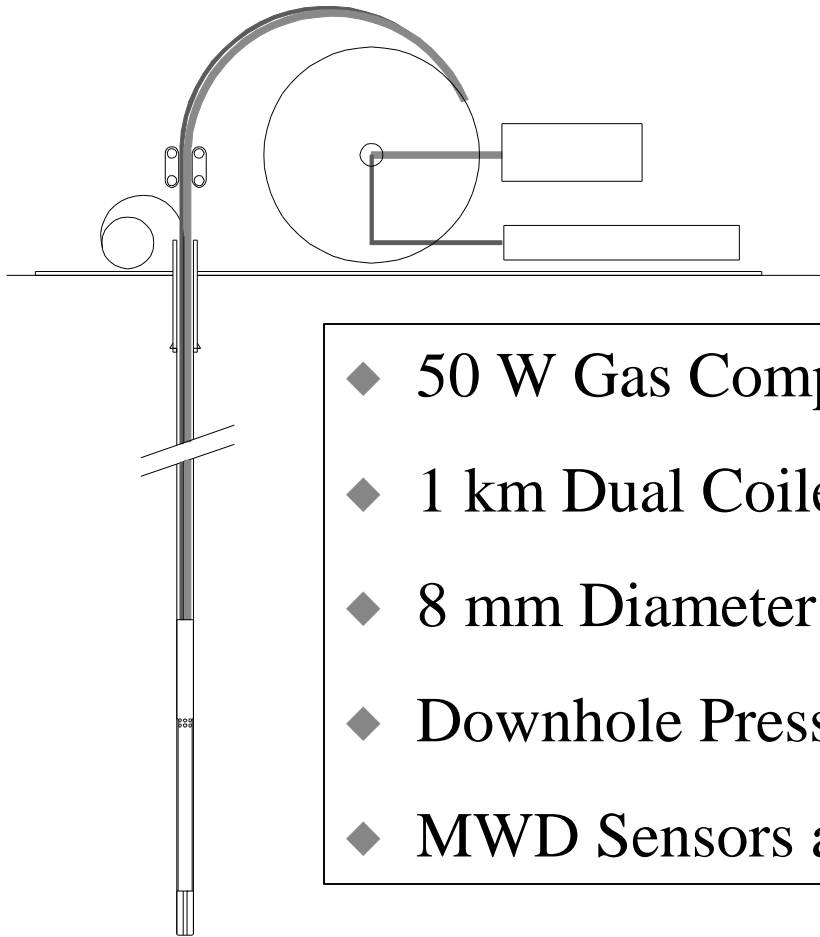
$$R_{gas} = 189 \text{ J/kg-}^\circ\text{K}$$

$$C_p = 845 \text{ J/kg-}^\circ\text{K}$$

Compressed CO₂ Drilling

- ◆ Meets Basic Drilling Requirements
 - Transmit power to drill bit - coiled tubing
 - Cut the rock - percussive or rotary
 - Transport cuttings to surface
- ◆ Autonomous Drilling System Issues
 - Hole diameter, depth and drilling rate
 - Hole stability
 - System weight and power
 - Development needs

Hypothetical Drilling System



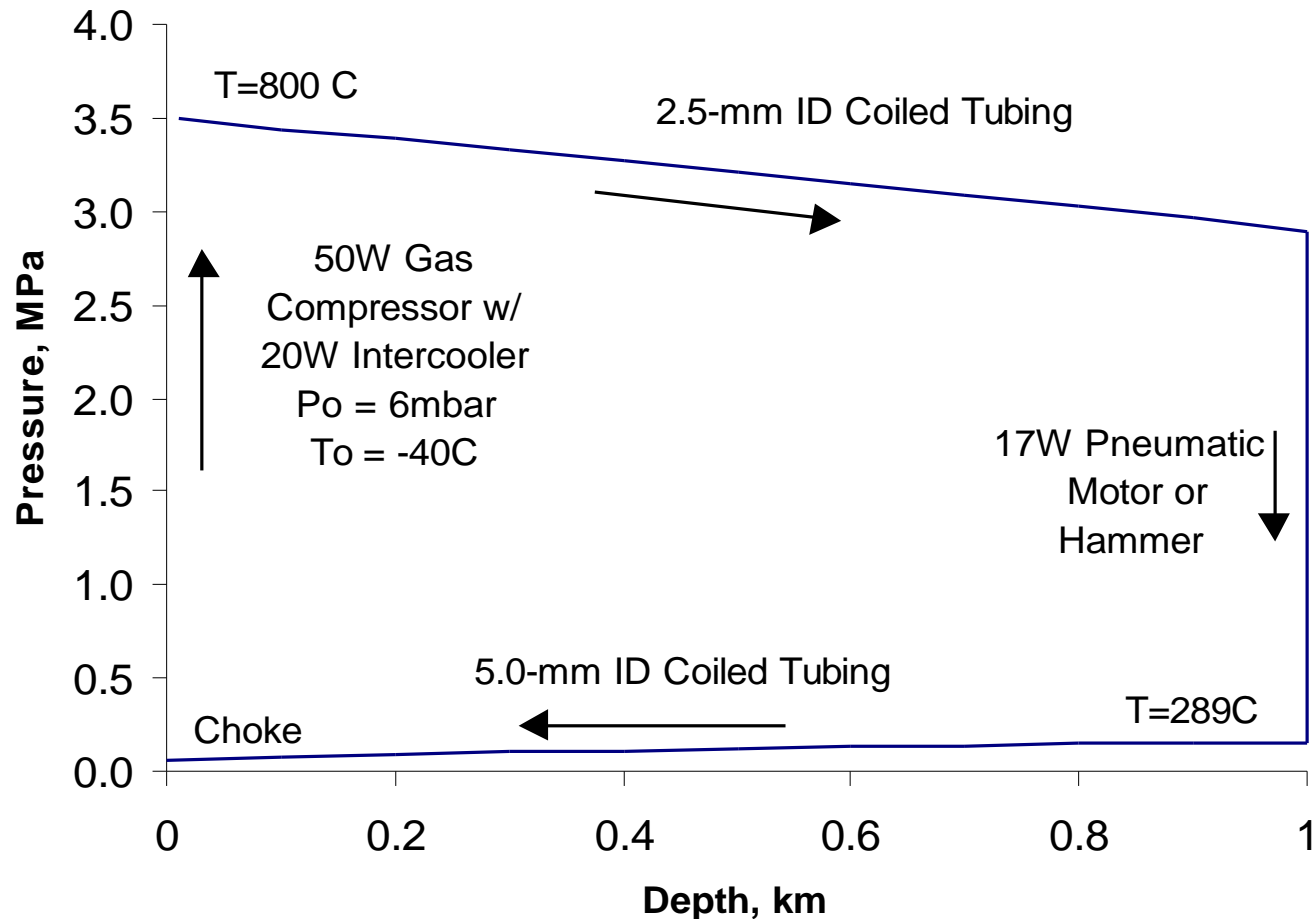
- ◆ 50 W Gas Compressor
- ◆ 1 km Dual Coiled-Tubing
- ◆ 8 mm Diameter Turbine or Percussion Drill
- ◆ Downhole Pressure Seal at 2 bars
- ◆ MWD Sensors and Cuttings Sensors

Gas Drilling Model

- ◆ Gas Compression
 - Multistage Turbine with Intercooler
- ◆ Frictional Duct Flow
 - Subsonic Adiabatic Fanno Line Analysis
- ◆ Turbodrill or Percussive Hammer
 - Isentropic Multistage Expansion
- ◆ Cuttings Lift
 - Stoke's Drift in Pressurized Conduit

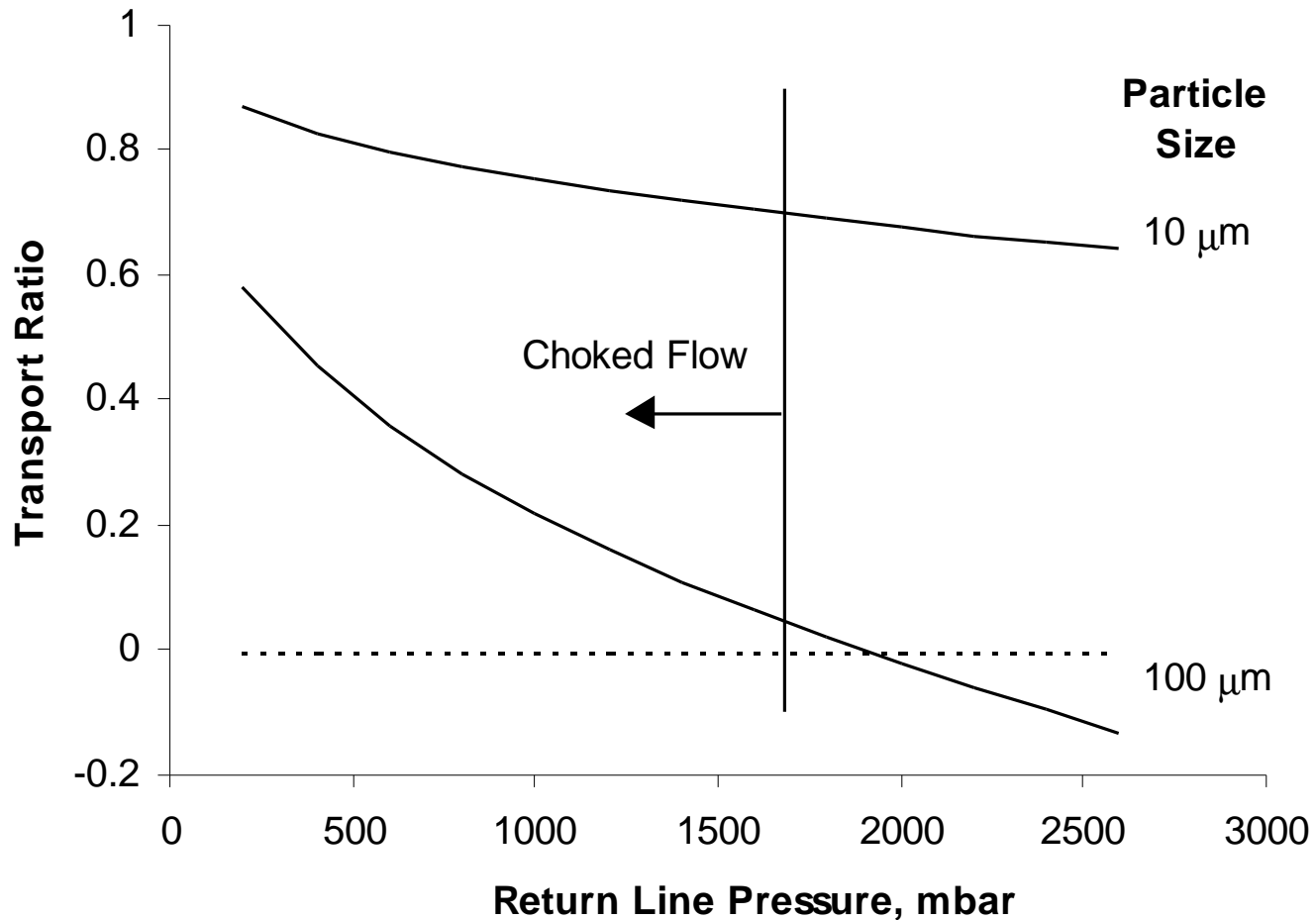
Gas Dynamics Model

50 W Hypothetical Drilling System

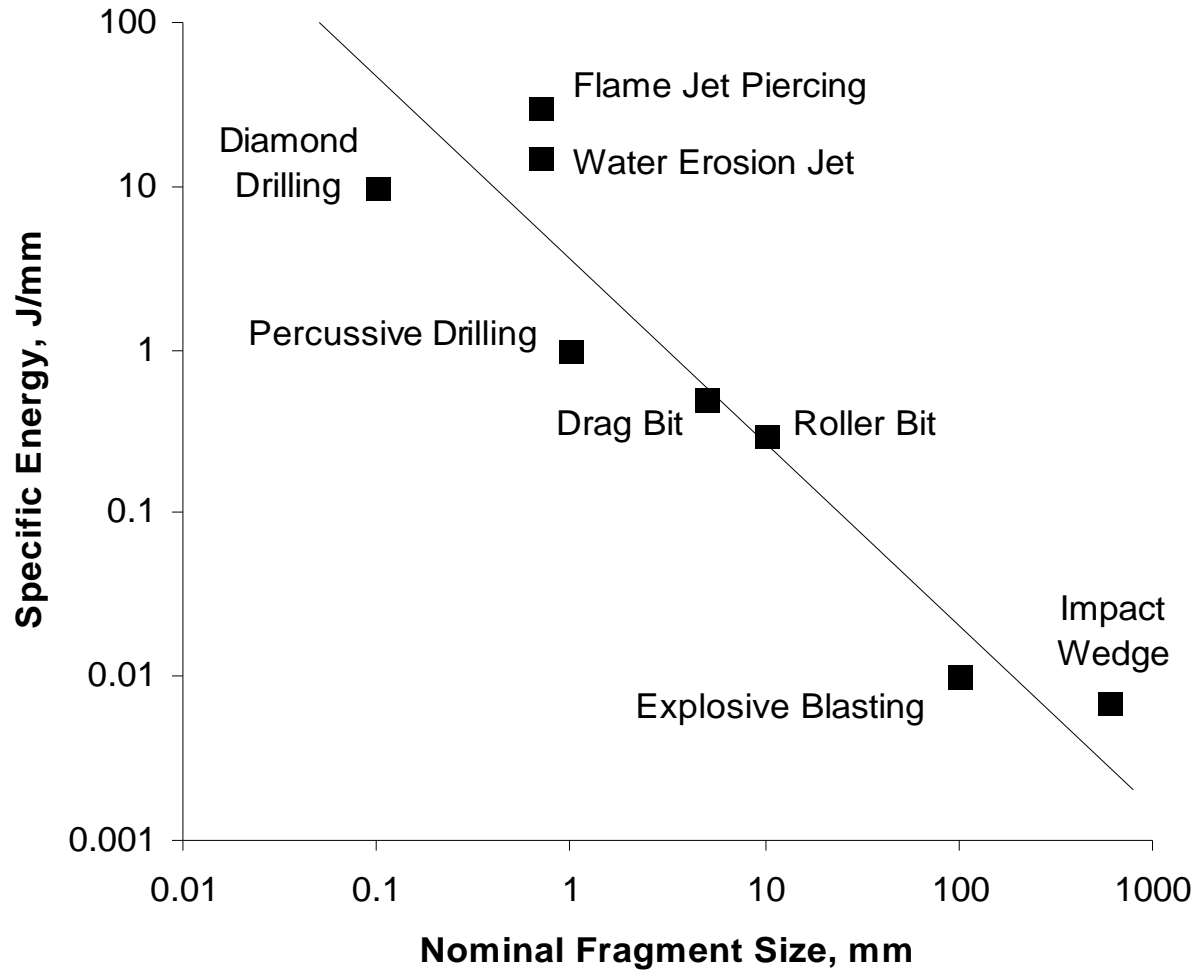


Cuttings Transport

50 W Hypothetical Drilling System

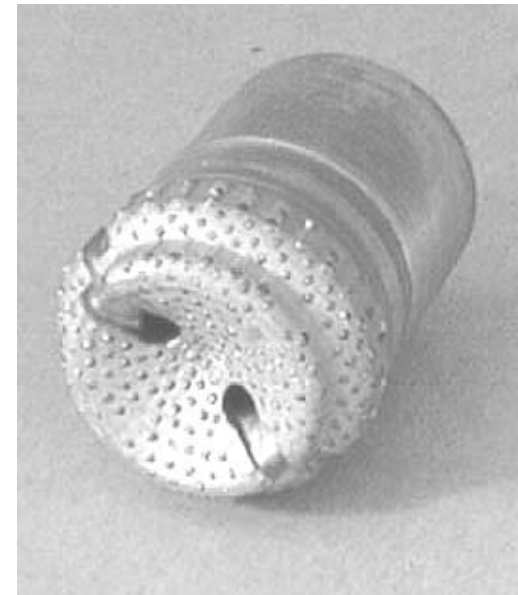


Specific Energy of Drilling



Mechanical Drilling Parameters

- ◆ Penetration Rate - 1 km per Year
 - 16 W mechanical power
 - 8-mm diameter hole
 - Specific energy is 10 J/mm^3
- ◆ Surface-Set Diamond Bit
 - 17 N (5 kg) thrust
 - 0.1 N-m torque at 1800 rpm



25-mm Diameter
Surface-Set
Diamond Bit

System Mass

Compressed CO ₂ Feed Tube	4 kg
Return Tube	7 kg
Bottom Hole Assembly	9 kg
<i>Downhole Total</i>	20 kg
Surface Equipment	??
<i>System Total</i>	< 50 kg

Drilling R&D Needs

- ◆ Miniature multistage gas turbine or hammer
- ◆ Rotary or percussive drill bits
- ◆ High temperature coiled tubing
- ◆ Heat transfer in gas lines
- ◆ Downhole pressure seal
- ◆ System engineering

Conclusions

- ◆ Deep drilling with a low-power, compressed CO₂ system is feasible
 - 10 mm diameter
 - Under 100 W power
 - Under 100 kg mass
 - 1 km per year
- ◆ Requires high temperature tool development