On the Extraction of Lunar Volatiles from Lunar Regolith Using Solar Power

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Agenda

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- Goals
- Concept
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- Results and Discussions
- Conclusions
- Future Plan

Introduction

- In-Situ Resource Utilization (ISRU)
  - "Living off the Land"
  - Produce resources for future outpost on the Moon and eventually Mars and asteroids
  - Less mass, energy and money
- Center for Space Exploration Technology Research at UTEP
  - Sponsored by the NASA Office of Education
  - ISRU is one of the research areas
- ExoTerra Resource LLC
  - Goal: to become the world's first space "utility" company
    - Power
    - Propellant
    - Water
    - Air

Background of Project

- Lunar Crater Observation and Sensing Satellite (LCROSS) and Lunar Reconnaissance Orbiter (LRO) mission
- Deep and long shaded craters can act as cold storage.

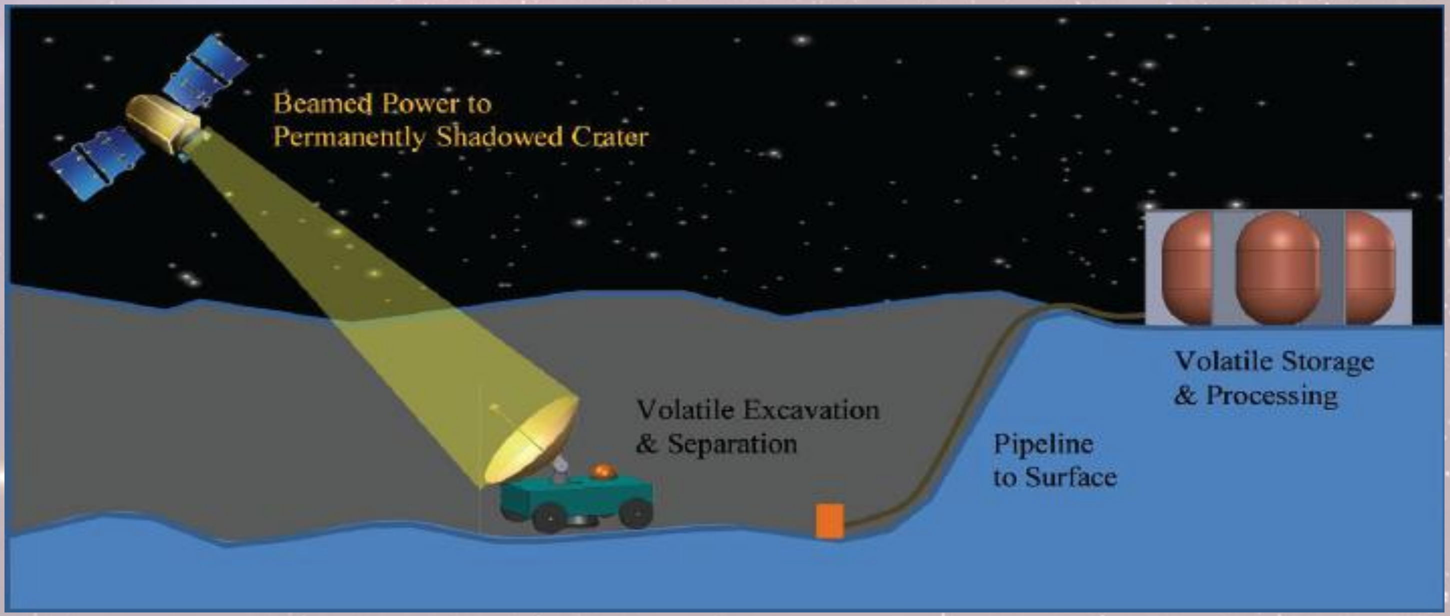
Image Source: http://www.youtube.com/watch?v=up1h-ziAK5E

Goals

- Extraction of water and other useful volatiles from Lunar regolith
  - Volatiles are compounds that freeze and are trapped in the cold lunar craters and vaporized when warmed by the Sun
    - Water
    - Nitrogen
    - Hydrogen
    - Carbon monoxide
    - Chlorine
    - Ammonia
- Project investigates methods for the extraction of volatiles using solar power.

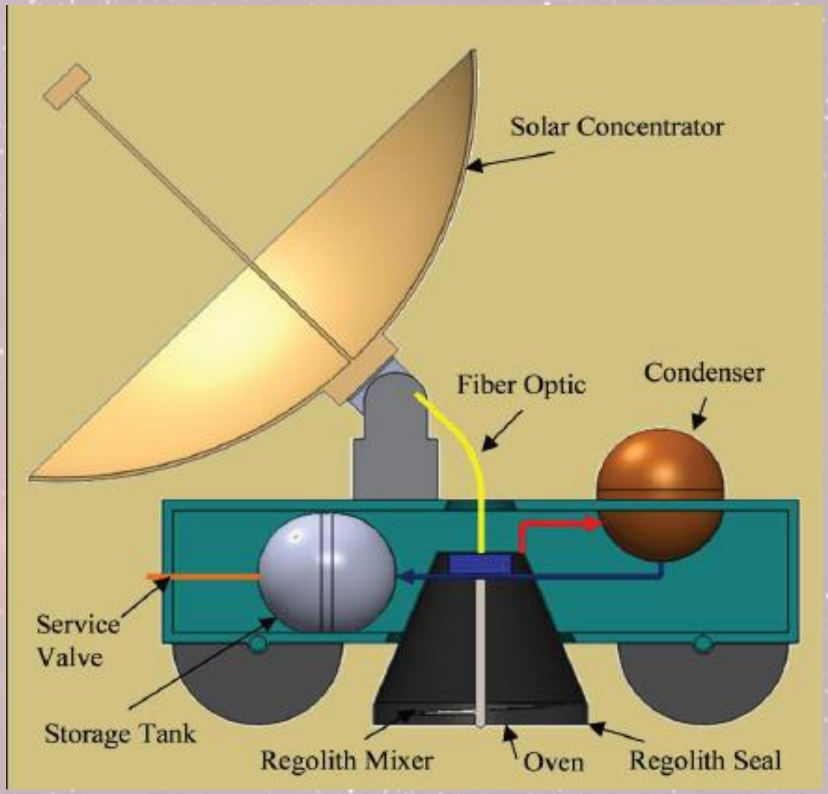
Concept

- Perform the transfer of beamed solar power from concentrators locater either onboard orbiters or on top of the crater walls

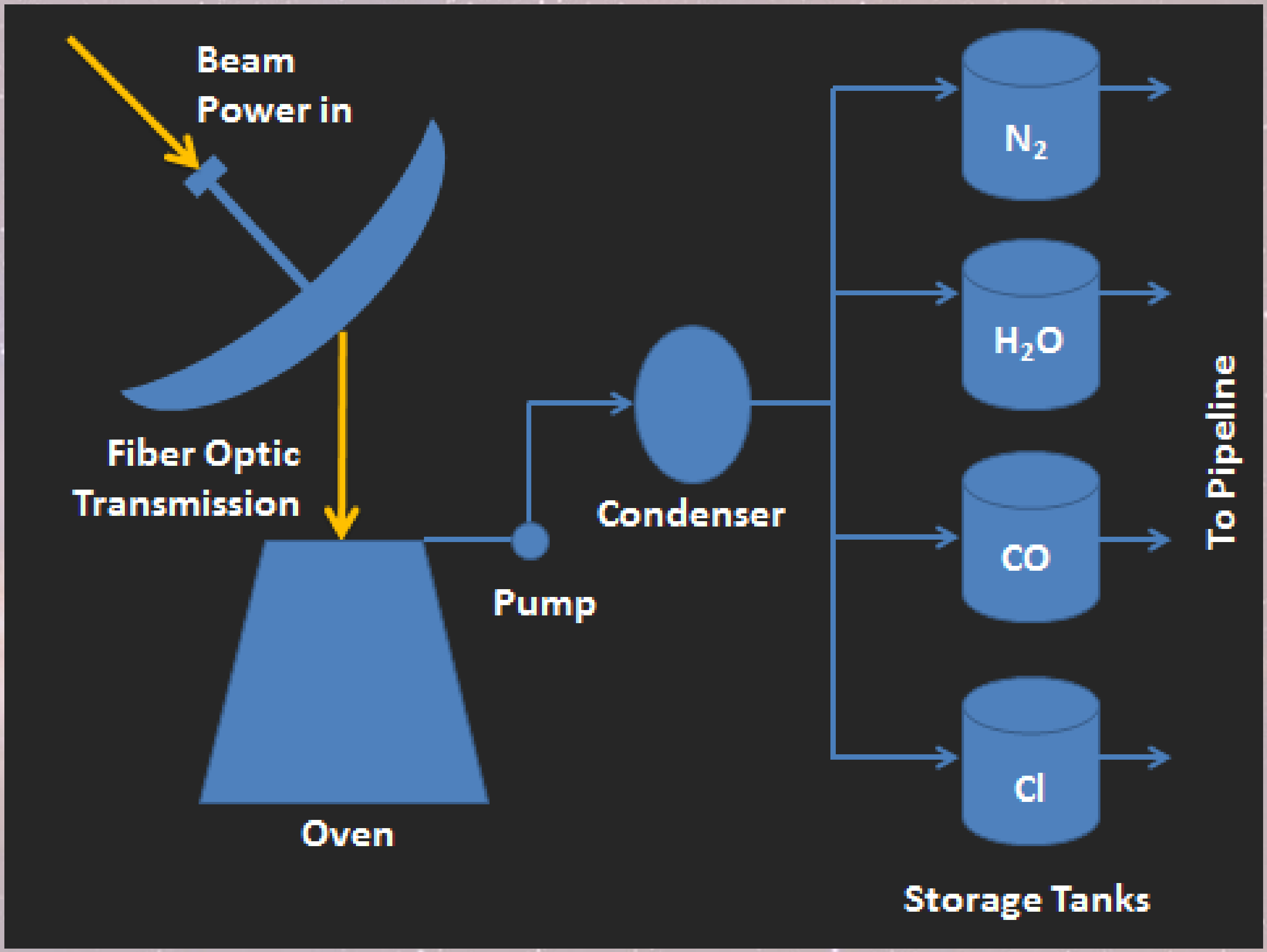


Concept

- A preliminary design for the extraction system
- Includes an oven heated by solar power transferred by the fiber optics from the solar concentrator.



Concept



Beam
Power in
Fiber Optic
Transmission
Oven
Pump
Condenser
N_2
H_2O
CO
Cl
To Pipeline
Storage Tanks

Challenges

- Low pressure and low temperature
  - Temperature and atmospheric pressure in the craters of the Moon are 40 K and 10^{-7} Pa, respectively.
  - Phase diagram of water at this conditions

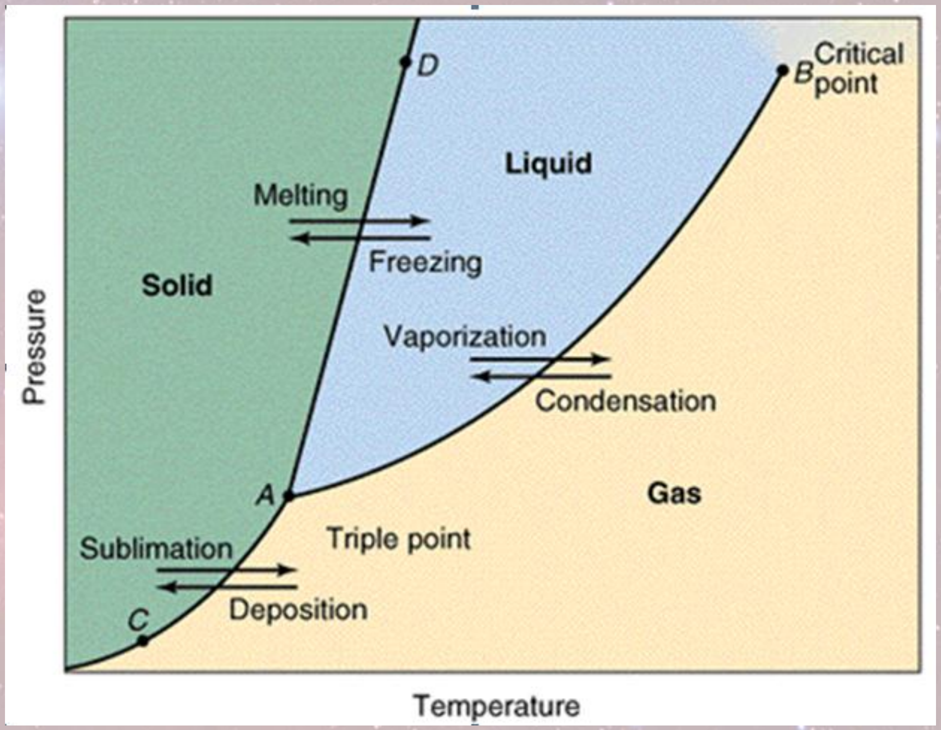


Image Source: http://itl.chem.ufl.edu/2041_u99/lectures/lec_f.html

Research Objectives

- Develop a steady model for heat transfer in a regolith layer that is irradiated by a beam of concentrated solar power
- Estimate the depth of regolith layer heated up to the boiling point of water at the atmospheric pressure of the Moon

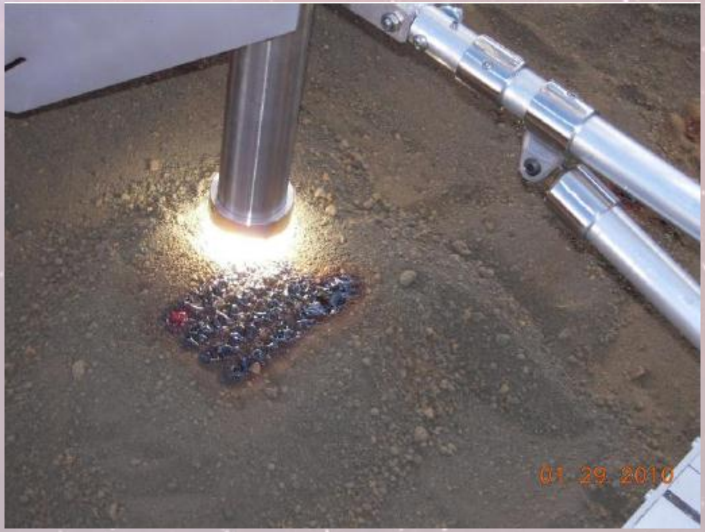
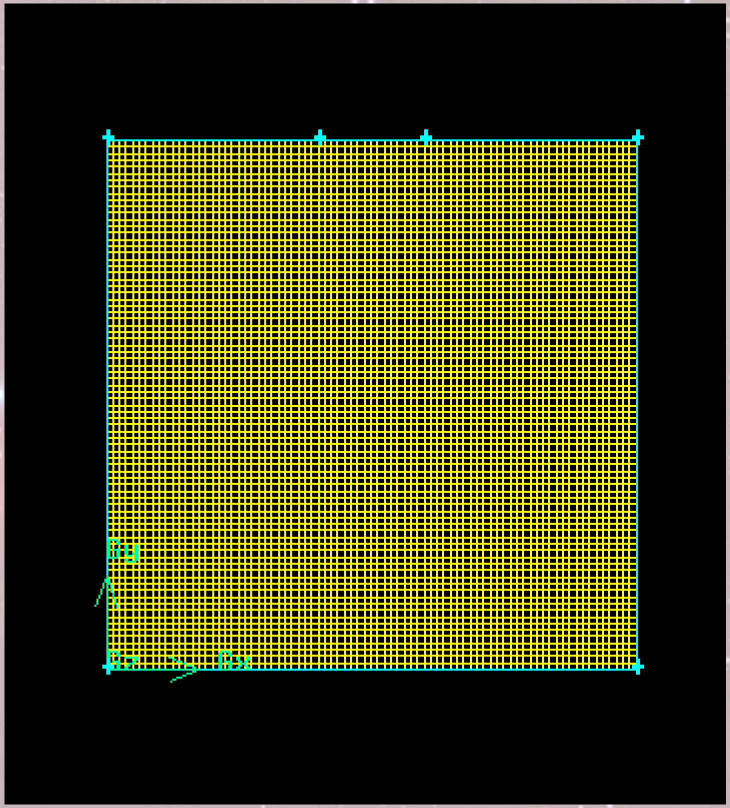


Image Source: Nakamura and Smith

Design Approach

- A two-dimensional model for heat transfer was developed using GAMBIT
  - 1 m x 1 m square
  - Mesh size of 2mm

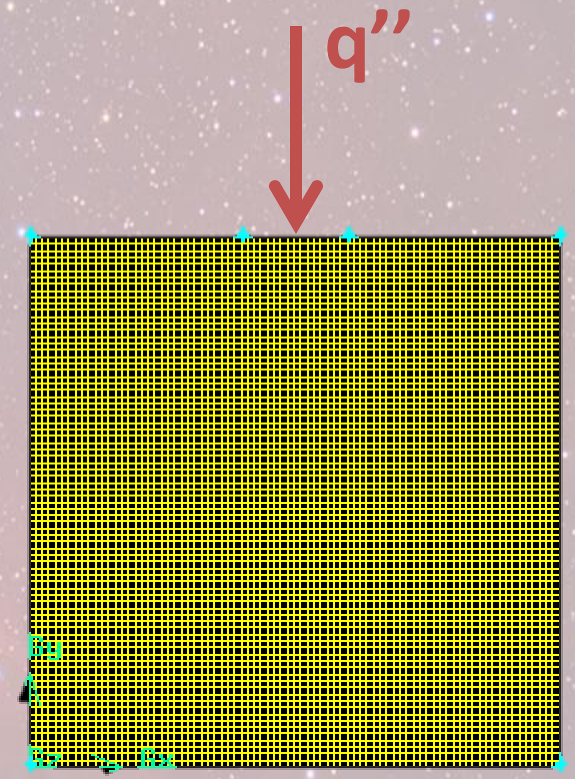


Boundary Conditions

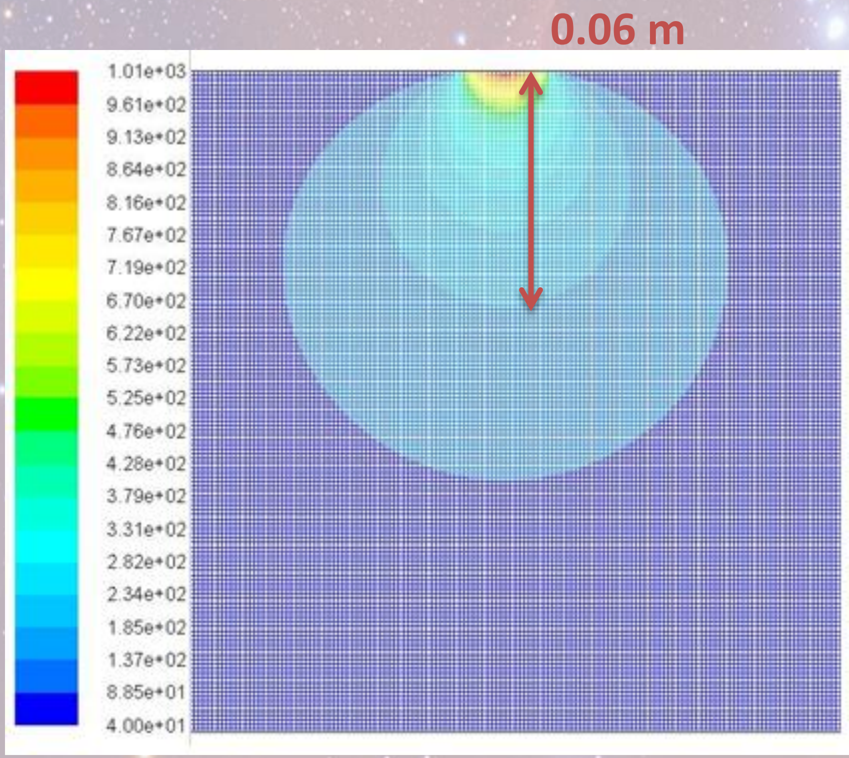
- After the GAMBIT model was created, it was imported into ANSYS FLUENT software.
- Boundary conditions were assigned to the simulation.
  - Density: 1660 kg/m^3
  - Specific heat: 840 J/Kg-K
  - Thermal conductivity: 0.01 W/m-K
  - Temperature: 40 K

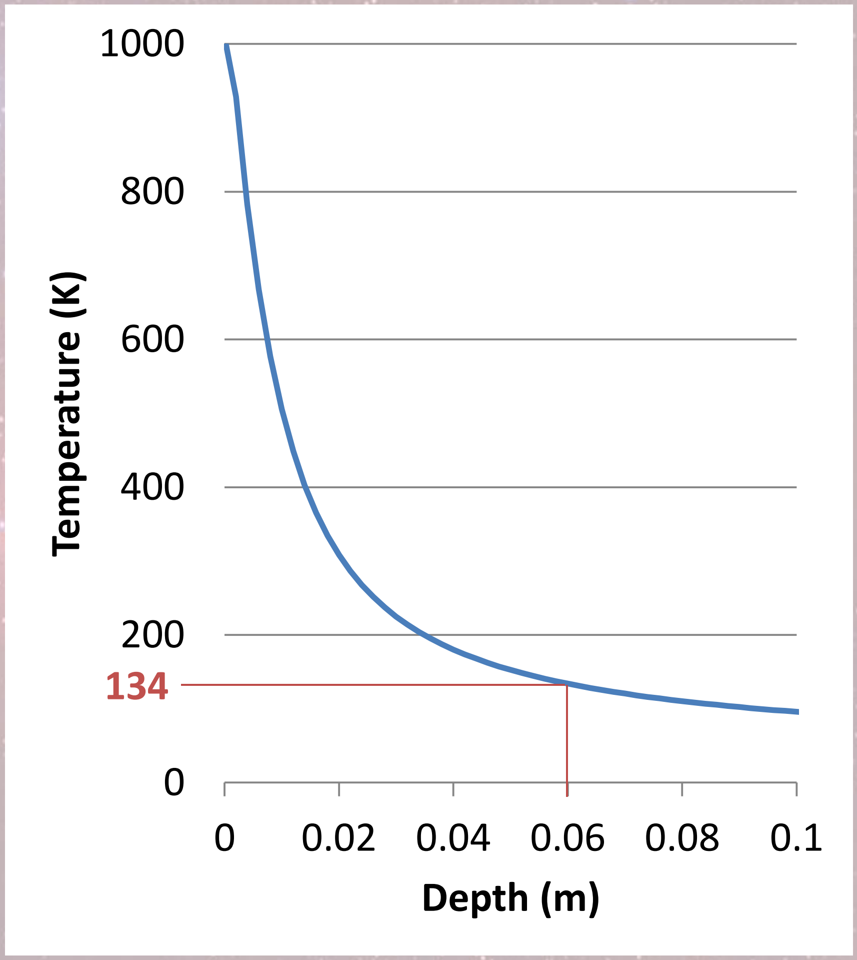
Test Plan

- Different values of the light heat flux were tested
- Heat Flux (W/m^2)
  - 125
  - 250
  -
  -
  -
  - 2375
  - 2500



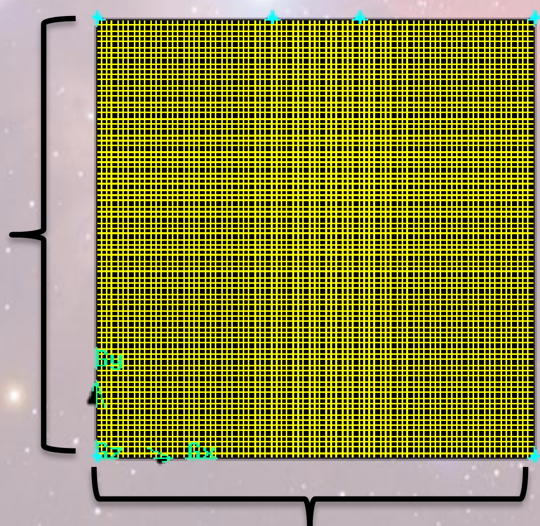
Temperature Field in Regolith at Heat Flux of 1000 W/m²



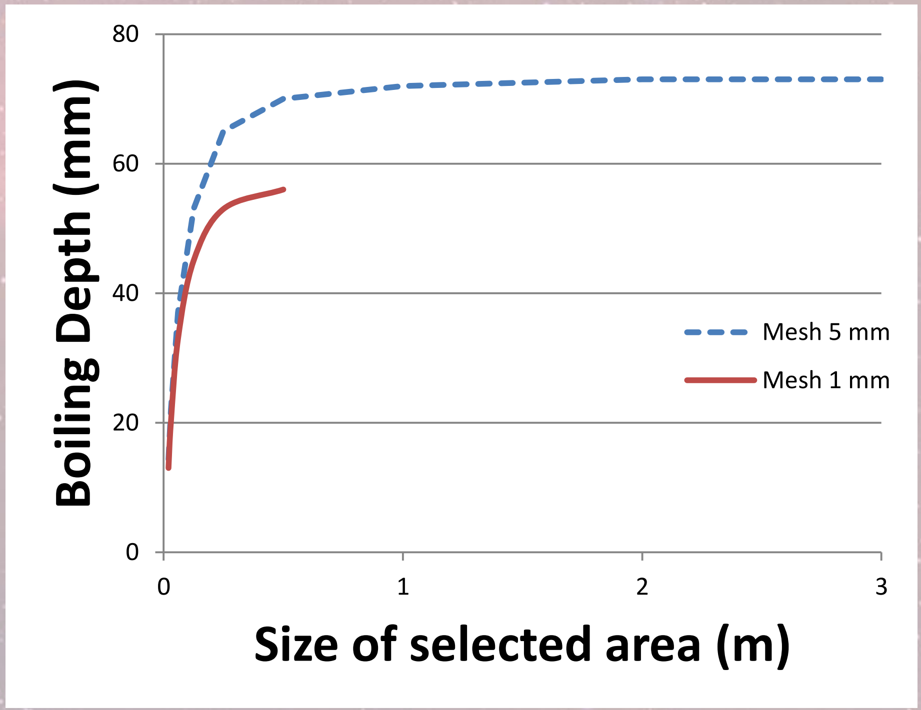


Size of the Selected Area

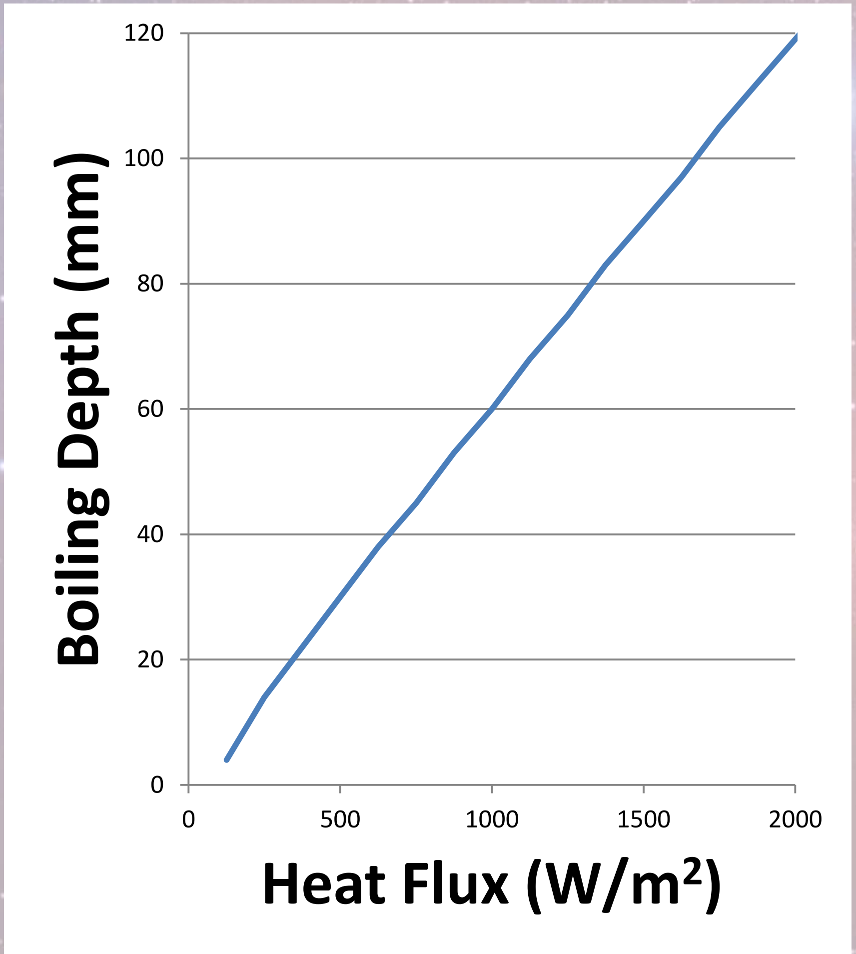
- For accurate calculations, the size of the selected area should be sufficiently large, so that the mesh size does not affect the results



Size of selected area (m)

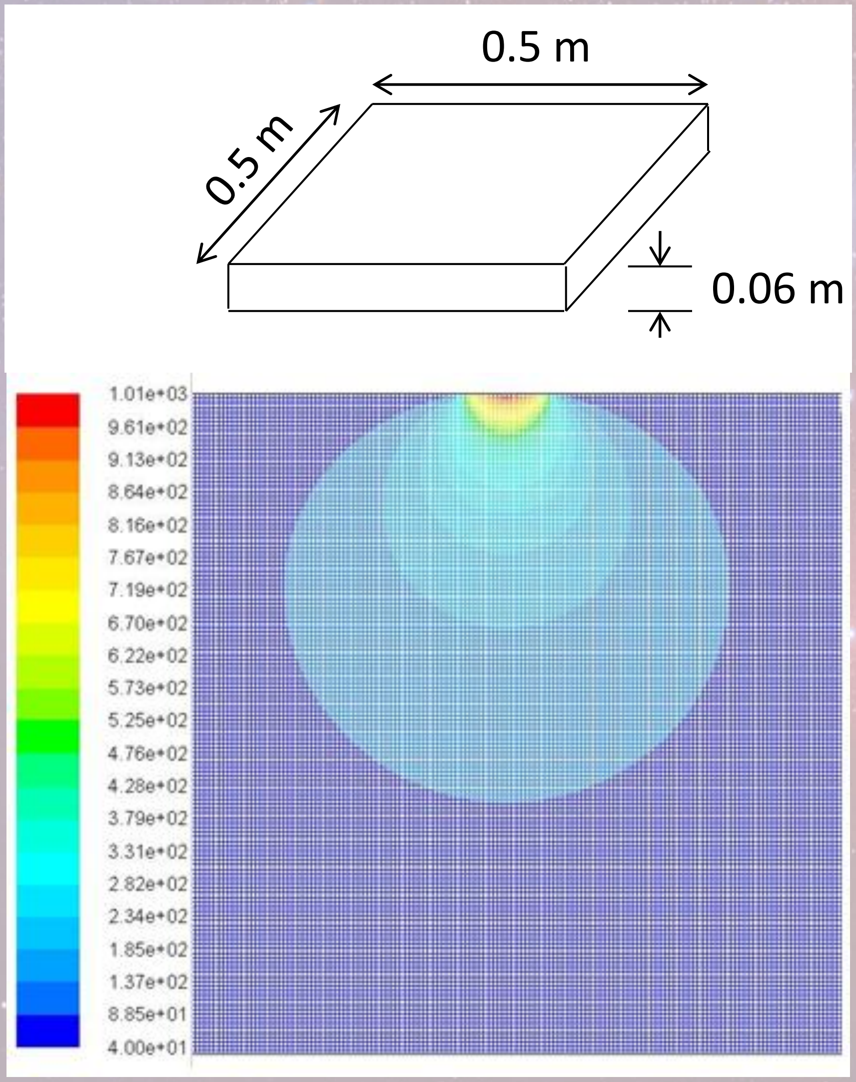


Effect of Heat Flux on the "Boiling Depth"



- Different heat fluxes applied to same size area.
- By increasing the heat flux, the "boiling depth" increases.

Estimation of Heated Mass for 1000 W/m^2



- If we heat a top area of 0.5 m x 0.5 m
- Multiply by 0.06 m
  - Volume: 0.015 m^3
  - Density: 1660 kg/m^3
- Heated mass: 24.9 kg

Estimation of Extracted Water Mass for 1000 W/m^2

Element	Symbol	Soil mass abundance (%)	Mass obtained (Kg)
Water	H_2O	5.6	~1.39

- Heated mass 24.9 kg
- Using data from LCROSS on the mass fraction of water in the regolith, the mass of water that can be extracted was calculated.

Conclusions

- A two-dimensional steady model has been developed for heat transfer in lunar regolith irradiated by a beam of concentrated solar power.
- The model allows one to calculate the depth that can be heated to the boiling point of water or any other volatile at the atmospheric pressure of the Moon.
- By knowing the “boiling depth”, heated mass of regolith can be calculated.
- Using available data on the mass fractions of volatiles in the regolith, amounts of volatiles that can be extracted for the given heat flux can be determined.

Future Plans

- Transient heat conduction
- Physical experiment at room temperature and in vacuum
- Lunar volatile extractor prototype design
- Demonstrate condensation, separation, and storage of volatiles

Image Source: http://1.bp.blogspot.com/_-98-A6yribs/SpcJrN8vynI/

Acknowledgments

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Questions