3-D Additive Construction for Space – Solar Powered Materials Processing

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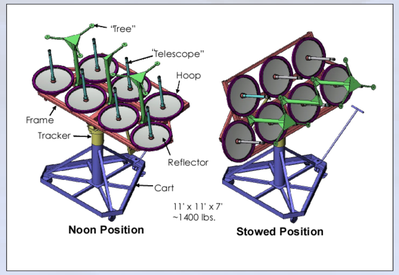
Solar Thermal Power System for ISRU Applications Field Deployment and Operation at Mauna Kea, HI

Presented at:
The Space Resources Roundtable (SRR) and The Planetary and Terrestrial Mining Sciences Symposium (PTMSS) June 8-10, 2010

Background

- Solar power is a readily available heat source for in-situ resource utilization (ISRU)
- During 1993-1996 Physical Sciences Inc. (PSI) developed a laboratory prototype of the optical waveguide (OW) solar power system for lunar material processing (SBIR Phases I & II by NASA/JSC)
- During 2007-2009, PSI developed the ground-based demonstration system (SBIR Phase III by NASA/GRC)
- The Phase III system was completed in March 2009 and has been tested at ORBITEC for the carbothermal oxygen production program

Solar Concentrator Array with Seven Reflector

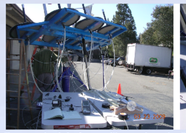


Solar Concentrator Tested at PSI: March 2009


Seven concentrators mounted on the tracking array

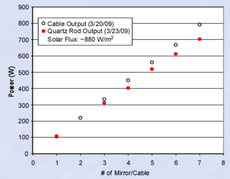

Back of the array with reactor interface

Solar Concentrator: Reactor Interface


The reactor interface with quartz rod


The quartz rod emitting solar radiation

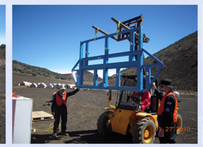
Solar Concentrator Power Output Fiber Cable vs. Reactor Input Optics



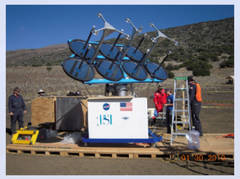
	Concentrator/Cable (3/20/09)	Quartz Rod (3/23/09)
Ambient Solar Flux (W/m^2)	880	880
Power (W)	795	795
System Efficiency (%)	37.8	37.8

Solar Concentrator System Integrated with the ORBITEC Carbothermal Reactor

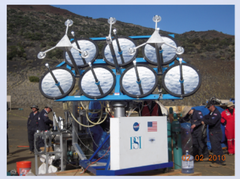
Assembling the Solar Concentrator Array at Mauna Kea Test Site

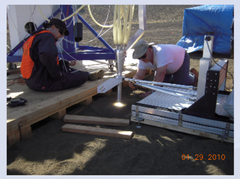
Solar Concentrator Array Preparing for Solar Sintering of Tephra



Afternoon Cloud Diminishing the Solar Power



PSI Solar Concentrator Integrated with NORCAT Rastering System



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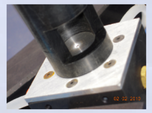
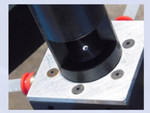
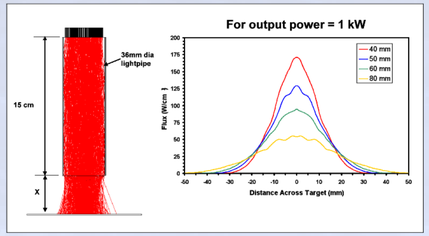
Measurement of Ambient Direct Solar Flux

Date	Ambient Solar Flux (W/m^2)	Comment
1/28/10	821	Clear but overcast
1/29/10	872 ~ 992	Thin high cloud
1/30/10	821 ~ 889	Partially cloudy
1/31/10	889 ~ 1006	Overcast with high cloud
2/1/10	434 ~ 650	Cloudy
2/2/10	684 ~ 1078	Clear at noon, high cloud towards the end of the day
2/3/10	1000 ~ 1026	Clear
2/4/10	914 ~ 1034	Clear
2/5/10	995 ~ 1078	Clear
2/6/10	944 ~ 1060	Clear
2/8/10	981 ~ 1033	Clear
2/9/10	872 ~ 1051	Warm, Clear with thin high cloud

Ray-Tracing for Sintering Rod

Note: Rod Length 15 cm is for ray-tracing, not actual hardware

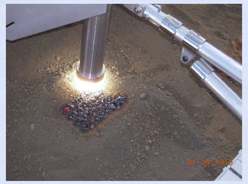


One-Color Optical Pyrometer

- Raytek MMG5H
- 5 micron measurement
- Solar energy doesn't interfere with the measurement
- Sensor was calibrated for emissivity at 550 °C

Sintering Quartz Rod Assembly Photo

Melting Tephra



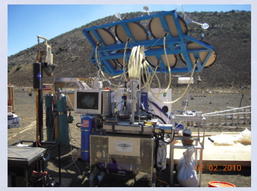
Process Optimization

- 500 W – 560 W power in full sun
- 2 in from tephra surface
- Temperatures reached more than 1300° C at steady state
- Multiple trials at different speeds and distances
- 2.35 mm/sec produced ~1100° C surface temperatures consistently

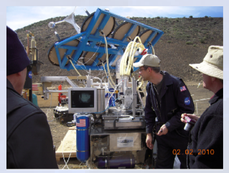
15" x15" Sintered Test Patch

Sintered Patch After Thruster Firing


PSI Solar Concentrator Integrated with ORBITEC Carbothermal Reactor



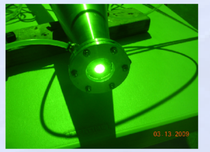
PSI Solar Concentrator Integrated with ORBITEC Carbothermal Reactor

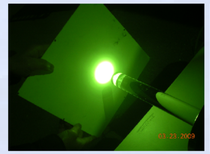

CT reactor displaying the Tephra melt on screen


Tephra melt temperature (°C)

CT Reactor Melts


Power Output Measurement



Cable Output



Quartz Rod Output

Summary

- **PSI team deployed and operated the solar concentrator system in environments that are not encountered in laboratory test setting**
  - Solar flux varied in a broad range (450~1050 W/m^2)
  - Dust effects on primary reflector and cable inlet
  - Freezing temperature in the night
- **PSI/NORCAT Team demonstrated solar sintering of Tephra**
  - Lunar surface stabilization with solar thermal sintering of regolith
  - Sintered a 15 in x 15 in Pad
  - Single layer due to time constraint
- **PSI/ORBITEC Team conducted a series of Carbothermal (CT) oxygen production experiments**
  - Tephra melt at 1700~1800° C
  - 16 successful CT reaction tests

Acknowledgments

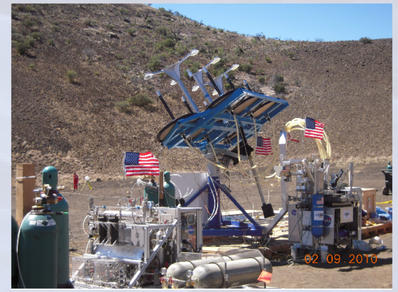
- **The PSI team would like to thank those who helped us in preparation, setup, deployment and operation of the solar concentrator**
- **Collaborations with NORCAT and ORBITEC personnel have been very effective, stimulating and rewarding**
- **Our participation in the ISRU Analog Test, Mauna Kea, HI was made possible by the Phase III SBIR contract administered at NASA/KSC (mnk10ea03P), Dr. Anthony Muscatello, the technical contact**
- **The solar concentrator system deployed at Mauna Kea was developed under the SBIR Phase III program supported by NASA/GRC, Dr. Aloysius Hepp, the technical contact**

Dust on the Primary Mirror


Dust Deposit on the Primary Concentrators


Seven Primary Concentrators Cleared of Dust Deposit
• 10% Power Increase by Cleaning

Remote Operation from NASA/JSC


PSI Solar Concentrator (middle), ORBITEC CT Reactor (right) and NASA/JSC Water Electrolizer (left) operated remotely from Houston, TX

This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, US Department of Agriculture under Agreement Number 2009-33610-19676 of the Small Business Research Grants Program. Any opinions, finding, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the view of the US Department of Agriculture.