Pneumatic Regolith Transfer Systems for In Situ Resource Utilization

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Presented by Van Townsend, NASA Kennedy Space Center, Florida USA

AMS 2010
May 12–14, 2010
Orlando, Florida
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Regolith Transfer and ISRU Processing Steps

1. Excavator Delivers Regolith to Trough
2. Regolith is Transferred to the Pneumatic Transfer System's Supply Bin
3. Regolith is Conveyed Pneumatically to an ISRU Reactor
4. Spent Regolith is Pneumatically Conveyed Out of the ISRU Reactor
5. Regolith is Chemically Reacted to Yield Useful Products Like Oxygen and Metals such as Titanium
   - E.g., Carbothermal, Hydrogen Reduction, Molten Oxide Electrolysis
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Possible Regolith Feed Systems

<table>
<thead>
<tr>
<th>Pneumatic Transport</th>
<th>Inclined Auger</th>
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<tbody>
<tr>
<td><strong>Pros</strong></td>
<td><strong>Pros</strong></td>
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<tr>
<td>+ Compact</td>
<td>+ Simple</td>
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<tr>
<td>+ Versatile - easily reconfigurable to fit other systems</td>
<td>+ Previous experience</td>
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<tr>
<td>+ Low temperature valves</td>
<td>+ Sprawl (good for spent pile)</td>
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<tr>
<td>+ Improved performance in 1/6 g</td>
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<tr>
<td>+ System commonality – reuse of ISRU fluidization components</td>
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<tr>
<td><strong>Cons</strong></td>
<td><strong>Cons</strong></td>
</tr>
<tr>
<td>- Complexity</td>
<td>- Wear concerns</td>
</tr>
<tr>
<td>- Additional Cooling</td>
<td>- Sprawl (bad for volume and deployment concerns)</td>
</tr>
<tr>
<td>- Sandblasting</td>
<td></td>
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<tr>
<td>- Size Sorting</td>
<td></td>
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<tr>
<td>- Compressor required if not already available</td>
<td>- Dump pile interference</td>
</tr>
</tbody>
</table>
ROxygen Testing

Successfully Assembled and Tested ROxygen System:

• Successfully Assembled and Tested the subsystem at JSC to qualify for the OPTIMA Field Test
• Assembled the complete system in Hilo for the OPTIMA Field Test
• Successfully performed reductions to achieve our goal of producing water from dry native soil then separated that water into hydrogen and
ROxygen Testing

Valves that are compatible with the flow of granular materials. Figure: Spherical Disc Valve from Gemco, Inc
ROxygen Testing

Figure: Hot Tephra flowing out of Gemco valve attached to the bottom of the ROxygen I Reactor.
.Show Movie
ROxygen Testing

Figure: Flight experiment in May 2008 to test the flow of regolith simulant inside a hopper under reduced gravity conditions.
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Reduced Gravity Flight Experiment to Evaluate the Pneumatic Regolith Transfer System at 1/6 g and to Compare with Results at 1 g
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Pneumatic Regolith Transfer System for 1 g and 1/6 g

- HEPA Filters for Exhaust Air from Electrocyclone
- Cyclone/Electrocyclone Gas-Particle Separator
- Secondary Containment Enclosure w/Hinged Door (Total Weight: 195 kg)
- Regolith Supply Partially Hidden in Back (17kg of NU-LHT-2M)
- Receiving Bin (Empty) Serving as an ISRU Reactor Mockup
- Venturi Eductor (hidden) attached to Supply Bin for Gas-Solids Mixing
- High Voltage DC Power Supply for Electrocyclone
- Gas Supply (from Reg. Compressed Air Bottle)
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The NASA KSC Reduced Gravity Flight Experiment was supported by the NASA Innovative Partnership Program and flow from the JSC Reduced Gravity Office at Ellington Field in Houston
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Figure: Pneumatic Regolith Feed System for the Carbothermal O2 reactor at the Mauna Kea field test in February 2010. Pneumatic system tested in Feb 2010 at Mauna Kea.

Find a better picture and insert video

Get Rover delivering material
RESULTS

- Tephra (16.5kg) transferred well in 1 g
- Tephra (16.5kg) transferred better in 1/6 g

- NU-LHT-2M transferred well in 1 g. Sieved (1.4 mm) 12.5 kg was transferred in ~3 min in 1g.
- NU-LHT-2M (8.8kg) transferred better in 1/6 g (rocks in unsieved sample plugged the eductor that halted regolith transfer)

- Fluidization was evident
- Eductor formed a hole that collapsed as a result of fluidization

- Cyclones were overwhelmed by simulant flow (electrocyclone needs a dilute flow)
- Cyclones to be re-designed for dense flow
Conclusions

✓ Pneumatic regolith transfer was successfully demonstrated at 1 g and at 1/6 g.

✓ It is possible to pneumatically convey a dense flow of the lunar regolith simulants NU-LHT-2M and Tephra to a vertical height of 1.52 meters (limited by the aircraft).

✓ Since the RGF experiment hardware experiences periods of increased gravity (~1.8 g), this likely compacts the granular regolith simulant material.

✓ Turning off the flow of dusty gas between parabolas resulted in inefficient cyclone performance, and likely contributed to the cyclones being overwhelmed by the dust flow during the RGF experiment.
Conclusions

✓ Cyclone separators are essential to a closed-loop pneumatic regolith transfer system in which the gas must be reused.

✓ Reduced gravity flight experiments and ground tests demonstrated that lunar regolith simulant is very easily conveyed pneumatically into a simulated ISRU oxygen production plant reactor, and that the regolith can be fluidized within the hopper feed system. The ground testing demonstrated that regolith can also be expelled from the ISRU reactor for disposal (or possibly for later resource processing, e.g., to extract silica, aluminum, titanium, iron, etc.).
Future Work and Integration Plans

✓ Metering the regolith feed will make it possible to test the electrocyclone by producing a moderate dense flow of dusty gas that yields a sufficient mass transfer rate while lessening the burden on the cyclones to filter the exhausted gas.

✓ The results of these experiments influenced the design of the regolith feed systems of the ROxygen second generation oxygen production system being developed by the NASA ISRU project, as well as the Carbothermal oxygen production plant, which was recently field tested on Mauna Kea.

The ROxygen 1 Field Test used an Auger Regolith Feed System. ROx 2 design uses the Pneumatic Regolith Feed System.
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Acknowledgments

The NASA Innovative Partnerships (IPP) Program and the Facilitated Access to the Space Environment for Technology Development and Training (FAST) Program,

the Reduced Gravity Office (RGO) at NASA Johnson Space Center,

Structural analysis: Greg Galloway at NASA KSC (NE-S),

RGF Team: Dave McLaughlin and Adam Dokos of the NASA KSC Prototype Development Laboratory (NE-L3),

the NASA Kennedy Space Center CDDF program,

the ROxygen ISRU project under NASA ETDP,

the management of the NASA Lunar Surface Systems (LSS) Office,

the KSC Engineering Directorate (NE),

and the KSC Surface Systems Office (NE-S).
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Acknowledgments

Figure: Jet-Lift Regolith Transfer
Figure: Pneumatic Regolith Feed System for the Carbothermal O2 reactor at the Mauna Kea field test in February 2010.

Pneumatic system tested in Feb 2010 at Mauna Kea.

Find a better picture and insert video
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