The atmosphere of Mars has many resources that can be processed to produce things such as oxygen, fuel, buffer gas, and water for support of human exploration missions. Successful manipulation of these resources is crucial for safe, cost-effective, and self-sufficient long-term human exploration of Mars. In our research, we are developing enabling technologies that require fundamental knowledge of adsorptive gas storage and separation processes. In particular, we are designing and constructing an innovative, low mass, low power separation device to recover carbon dioxide and carbon monoxide for Mars ISRU (in-situ resource utilization). The technology has broad implications for gas storage and separations for gas-solid systems that are ideally suited for reduced gravitational environments. This paper describes our separation process design and experimental procedures and reports results for the separation of CO$_2$ and CO by a four-step adsorption cycle.
As illustrated in Figure 1, this work comprises one-third of an overall process for producing O₂ and CO at moderate pressures from the Martian atmosphere. An adsorption compressor, developed by Dr. John E. Finn at NASA Ames Research Center, adsorbs CO₂ from the atmosphere and compresses it to a pressure of 1 bar. The CO₂ is then passed to a solid oxide electrolysis cell developed by K. R. Sridhar at the University of Arizona. This electrolysis cell makes use of yttria-stabilized zirconia to produce oxygen from the compressed planetary CO₂ and will then reject CO and unreacted CO₂ in a separate stream. The efficiency of the oxygen-production process is greatly improved if the unreacted CO₂ is separated and recycled back into the feed stream. The separation will also have a positive impact on the mass of the adsorption compressor because less CO₂ will needed from the atmosphere. Additionally, the CO by-product is a valuable fuel for space exploration and habitation, with applications from fuel cells to production of hydrocarbons and plastics.

Our separation device contains a CO₂-selective sorbent such that when the mixture is fed from the electrolyzer, CO₂ adsorbs and CO passes through the bed with minimal adsorption. The cycle is illustrated by Figure 2. The mixture is fed at a temperature of 273K. When the bed reaches capacity, it is isolated and heated with no flow at 398K to desorb the CO₂. CO₂ at high pressure is then allowed to pass to a storage tank at sufficient pressure to feed the electrolyzer. The bed is then cooled back to 273K prior to returning to the feed step. We envision a two-bed system in which one bed is onstream for the feed step while the other is undergoing regeneration and blowdown of CO₂.

![Figure 2: Depiction of four-step adsorption cycle between CO₂ adsorption isotherms on NaY zeolite.](image)

We have a working prototype and have performed the proposed cycle. We have developed process models and are continuing to optimize the separation. All of these results will be discussed.
Separation of Carbon Monoxide and Carbon Dioxide for Mars ISRU
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ABSTRACT
The atmosphere of Mars has many resources that can be processed to produce useful materials like oxygen, fuel, buffer gas, and water for support of human exploration missions. In this research, we are designing and constructing an innovative, low mass, low power separation device to recover carbon dioxide and carbon monoxide for Mars ISRU (in-situ resource utilization). The separation is accomplished by a four-step adsorption process. The technology has broad implications for gas storage and separations for gas-solid systems that are ideally suited for reduced gravitational environments.

Overall Process Description
Adsorption Compressor

Yttria-Stabilized Zirconia
Electrolyzer
Dr. K. R. Sridhar
University of Arizona

Mars Atmosphere
95% CO2
3% N2
2% Ar
0.007 bar

N2-Ar
Sorbert bed with high capacity for CO2
External D.C. voltage source

CO2 Compressor
50 mol% CO2

Adsorptive Separation
CO2-selective sorbent

Environmental Chamber

Helium/CO2 Feed

Gas Chromatograph

GC

The device is heated or cooled by an environmental chamber. Mass flow controllers allow constant flow of the mixture at prescribed rates. A mass flow meter measures the product flow and a pressure controller maintains downstream pressure at setpoint. An additional mass flow controller is used to control the flow to CO2-selective sorbent. A gas chromatograph allows analysis of the composition of the product stream. The process is automated by National Instruments LabView software.

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