AIAA 97-2763
Adsorption Compressor for Acquisition and Compression of Atmospheric $C0_2$ on Mars

Donald Rapp and Paul B. Karlmann
Jet Propulsion Laboratory
Pasadena, CA

David L. Clark and Chad M. Carr
Lockheed Martin Astronautics
Denver, CO

33rd AIAA/ASME/SAE/ASEE
Joint Propulsion Conference and Exhibit
July 6-9, 1997 /Seattle, WA

For permission to copy or republish, contact the American Institute of Aeronautics and Astronautics
37o L'Enfant Promenade, S. W., Washington, D.C. 20024

ADSORPI’1ON COMPRESSOR FOR ACQUIS1TION AND COMPRESSION OF ATMOSPHERIC CO_2 ON MARS

Donald Rapp and Paul B. Karlmann
Jet Propulsion Laboratory
Pasadena, California

David L. Clark and Chad M. Carr
Lockheed Martin Astronautics
Denver. Colorado

Abstract

A flight-prototype zeolite adsorption compressor is being developed as a reliable, efficient, cost-effective means of extracting and compressing atmospheric CO_2 on the surface of Mars for use as the first stage of a Mars in-situ CO_2 to O_2 chemical conversion process.

By exposing the sorption compressor to the cold nighttime environment of Mars (typically 6 torr, 200 K), atmospheric CO_2 is preferentially adsorbed by the zeolite sorbent material contained within. During the daytime, when solar power is available, the sorbent is heated in a closed volume, thereby pressurizing the desorbed gas for use in a CO_2 to O_2 conversion reactor.

While previous studies have demonstrated successful operation of a Mars adsorption compressor, there are still several important challenges remaining in the design of a long-life, highly-efficient adsorption compressor with minimum volume, mass, and power requirements. Some of these are:

- Sorbent material adsorption characteristics
- Preventing build-up of non-CO_2 gases
- Efficient daytime heating
- Effective nighttime cooling

The purpose of this paper is to describe the preliminary design of a full-scale Mars CO_2 adsorption compressor which is currently in fabrication and is scheduled for testing later this year.

Introduction

A flight-prototype adsorption compressor is being developed as a reliable, efficient, cost-effective means of acquiring and compressing atmospheric CO_2 on the surface of Mars. A preliminary design has been completed and we are now finalizing the design and beginning fabrication. Designed as the first stage of a Mars in-situ CO_2 to O_2 chemical conversion process, this work is part of a collaborative effort between Johnson Space Center (JSC), Jet Propulsion Laboratory (JPL), and Lockheed-Martin Astronautics (LMA).[1] The purpose of this effort is to address the technical challenges associated with the development of a flight adsorption compressor for Mars, to present a preliminary design for a full-scale prototype system, and to model the performance of such a system in the Mars environment. A full-scale engineering model of the adsorption compressor will be tested later this year in a simulated Mars environment in a chamber on Earth.

The atmosphere of Mars is known from Viking measurements[2] to have the approximate composition shown below.

Table 1. Composition of Mars Atmosphere.

Gas	Volume %
CO_2	95%
N_2	2.7%
Ar	1.6%
O_2	0.15%
CO	0.06%
H_2O	0.03% (variable)

A variety of In Situ Propellant Production (ISPP) processes have been proposed for conversion of the CO_2 in the Martian atmosphere into O_2 and for some processes, a hydrocarbon fuel. These processes have the potential to provide considerable mass savings for Mars Sample Return (MSR) missions by using indigenous materials for propellants rather than materials brought from Earth. Although ISPP processes would provide

Copyright © 1997 by the American Institute of Aeronautics and Astronautics, Inc. No copyright is asserted in the United States under Title 17, U.S. Code. The U.S. Government has a royalty-free license to exercise all rights under the copyright claimed herein for governmental purposes. All other rights are reserved by the copyright owner.

significant mass savings, it would take typically 500-600 days of operation on the surface of Mars to produce enough propellant for the return flight from Mars to Earth. The need to operate an autonomous chemical conversion plant through 500-600 days of variable weather on Mars is a significant technical challenge.

The prevailing atmospheric pressure on Mars varies with location and season but a typical average value is roughly 6 torr.[2] For ISPP processes that require pressurized CO_2, the first step in the conversion process is acquisition of atmospheric CO_2 and compression from 6 torr to the higher pressure. Additionally, the compressor should be relatively small, lightweight, highly efficient, tolerant to dust contamination, capable of (at least partially) stripping out non-CO_2 gases, and rugged and reliable enough to operate for at least two years on the surface of Mars under significant daily and seasonal temperature variations.

One type of compressor which satisfies these requirements is a sorption compressor. Unlike a mechanical compressor, a sorption compressor contains virtually no moving parts and achieves its compression by alternately cooling and heating a sorbent material which absorbs low pressure gas at low temperatures and drives off high pressure gas at higher temperatures. Due to the minimal rotating/moving parts, it inherently has significant potential for increased lifetime, reliability, and robustness. Because the gas extraction and compression is achieved thermally rather than mechanically, there is also the potential of utilizing system waste heat for sorbent bed heating, thereby achieving improved system efficiency. Also, by utilizing the large daily temperature swing on Mars to contribute to the heating and cooling of the sorption compressor, increased energy efficiency can be realized.

By exposing the sorption compressor to the cold night-time environment of Mars (-6 torr, -200 K at moderate latitudes), CO_2 is preferentially adsorbed from the Martian atmosphere by the sorbent material. During the day when solar electrical power is available, the adsorbent is heated in a closed volume, thereby releasing CO_2 at significantly higher pressures (typically 200-2000 torr, as required) for use in a CO_2 conversion reactor.

An earlier prototype of this type of system was built and tested but a number of important challenges remain in the design of a long-life, highly efficient adsorption compressor with minimum volume, mass, and power requirements that were not addressed in the earlier work.

System Requirements

The basic sizing and overall design of the sorption compressor is driven by the required oxygen production rate for the ISPP system as well as the characteristics of the Martian environment. Although the requirements for any MSR mission are still in flux, preliminary estimates indicate the need to produce 1 - 2 kg/day O_2 depending on the mission design and the assumptions that are made. (Note that the actual production rate will vary with season and latitude).

If the zirconia process is used to produce oxygen, two molecules of CO_2 are required to produce one molecule of O_2. Allowing for various inefficiencies, 3 kg/day CO_2 are required to produce 1 kg/day O_2. However, if the Sabatier-Electrolysis process is used, this same compressor would produce slightly over 2 kg/day O_2.

Zirconia Process	$2CO_2 \rightarrow 2CO + O_2$
Sabatier-Electrolysis	$CO_2 + 2H_2 \rightarrow O_2 + CH_4$

Based on this information, a sorbent bed storage capacity of 3 kg/day CO_2 has been adopted.

Mars Environment

Much of the uncertainty associated with the design of a Mars adsorption compressor is due to the difficulty in predicting the highly variable environmental conditions on Mars. Shown below in Table 2, is a summary of typical ranges of Mars conditions used in the design of the sorption compressor.

Table 2. Typical Mars Environment.[3]

Atmospheric Pressure	5 - 8 torr
Daytime Air Temperature	180- 270 K
Nighttime Air Temperature	140-200 K
Effective Night Sky Temperature	130- 170K
Wind Speed	0 - 30 m/s
Atmospheric Composition	(see Table 1)
Avg. Dust Concentration	1×10^{-9} g/cm^3

Those aspects of the Mars environment which impact the performance of a CO_2 acquisition and compression system are the following:

Atmospheric Dust - The intake of dust into the system could potentially lead to problems such as leaky valves, fan failure, increased pressure drop, and poisoning of the sorbent material. For this reason, atmosphere entering the system must be effectively filtered for dust particles. Additionally, the settling of dust on photovoltaic and thermal radiating surfaces can potentially lead to long-term changes in the available power and heat rejection characteristics.

Atmospheric Pressure - The quantity of CO_2 adsorbed by the sorbent material is dependent on the adsorption pressure. Variation in the ambient atmospheric pressure will likely lead to variation in the daily amount of CO_2 acquired by the sorbent bed.

Local Thermal Environment - Local "air" temperature, wind speed, effective sky brightness temperature, and the incident solar radiation will all have a significant impact on the heat up and cooldown of the sorption compressor. Consequently, these factors will influence daily CO_2 capacity and required heater input power.

Atmospheric Trace Gases - Non-CO_2 gases such as N_2 and Ar have already been shown experimentally to affect the rate of CO_2 adsorption. However, it is not known what the long-term affects of trace gases such as H_2O will be. Over hundreds of days of cycling, will trace quantities (- .03%) of gases such as H_2O slowly degrade the sorption capacity of the sorbent material?

Operating Cycle

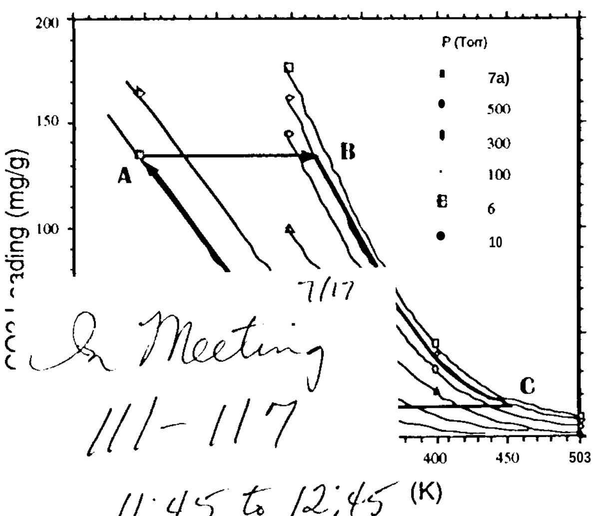
The idealized operating cycle for the Mars adsorption compressor is shown in Figure 1. In general, the temperatures, pressures, and timing of the cycle are determined by a combination of the sorbent material properties and the Mars thermal environment. The four basic steps of the cycle are the following:

(A→B) Heating at Constant Volume. Starting in the early morning at point "A" (195 K, 6 torr) with the zeolite material fully saturated with CO_2 and all valves closed, the bed is heated at a constant volume. Heating of the sorbent material drives off CO_2, thereby increasing the pressure within the closed volume. Eventually, at point "B" (- 320 K, -600 torr), the pressure has risen to a point where reactor operation is possible.

(B→C) Heating at constant Pressure. In the late morning, at point "B" (320 K, 600 torr), the valve to the reactor is opened, allowing CO_2 to flow through the reactor to produce OZ. To continually supply the reactor with CO_2 at a constant pressure, the sorbent bed is continuously heated under control by a pressure sensor. Gradually, the sorbent bed becomes depleted, and it takes higher and higher bed temperatures to maintain a constant supply pressure. By late afternoon, the sorbent bed reaches 450 K, whereupon the zeolite is essentially depleted (point "C"). At this point, the heaters are turned off and the valves are closed.

(C→D) Cooling at Constant Volume. By the end of the day at point "C" (450K, 600 tom), the heaters are off, all valves are closed, and the cooling cycle begins. Heat from the bed is dumped to a radiator, cooling the sorbent material. As the bed is cooled at a constant volume, CO_2 in the free volume of the bed is re-absorbed and the pressure decreases. Once point "D' is reached (350 K, 6 torr), the internal pressure of the sorbent bed is equal to the ambient pressure; therefore, valves to the Mars environment can be opened without losing gas from the bed.

(D→A) Cooling at Constant Pressure. For the remainder of the evening, the sorbent bed cools as heat is dumped to the radiator. Valves are open so that atmospheric CO_2 can enter and be adsorbed within the bed at a constant pressure of 6 torr. By the end of the evening, the sorbent material is fully saturated with CO_2 at 6 torr and -200 K (point "A"), and the entire cycle is ready to begin again.



F :ompressor basic operating cy'cle.

Sorbent Material Selection & Performance

The desired properties of the sorbent are that it absorbs as much CO_2 as possible at low temperature and pressure (near 200 K and 6 torr), and that it releases most of its CO_2 at a higher pressure (-700 torr) at the lowest possible temperature.

A literature search quickly revealed that the 13X and 5A classes of zeolites are good initial candidates for sorbents. Although there are many specially designed zeolites in the literature, some with favorable properties, preference was given to the commercially available 13X and 5A zeolites. Unfortunately, the data on these zeolites in the literature are in fragmented pressure and temperature regimes, and some conflicts exist between investigators.

Adsorption measurements for CO_2 at 6 torr and [95 K were made at JPL and are summarized in Table 3. Also, Dr. David Quinn of Royal Military College (RMC), Kingston, Ontario measured several isotherms for these materials at our request.[4]

Table 3. CO_2 adsorption (g/g) near 6 torr, 200 K.

Zeolite	JPL	RMC[4]	Ames[5]	UOP'
5A	0.14	0.09	0.18	- - -
13X	0.14	--	0.26	0.24

It is unclear why our data differ significantly from those of Refs. 5 and 6. For sizing of the sorption compressor, the JPL data was used. Although it is possible that the JPL data may underestimate the CO_2 capacity of the sorbent bed, this assumption will be checked during initial testing.

in general, 13X zeolite was found to be superior to 5A zeolite because it sheds CO_2 more easily at high T and P. From the JPL data, the quantity of CO_2 that can be obtained from 13X zeolite in a cycle from 195 K and 6 torr to 450 K and 500-700 torr is - 0.11 g CO_2 per g zeolite. An adsorption compressor for storing 3 kg of CO_2 would then require -28 kg of 13X zeolite.

Removal of Non-CO_2 Gases

Previous studies' have shown experimentally that CO_2 is preferentially adsorbed from a simulated Mars atmosphere consisting of a mixture of CO_2, N_2, Ar, and CO gases. This results in compressed CO_2 supplied to the reactor at significantly greater than atmospheric purity.

Unfortunately, the less-adsorbed gases such as N_2 and Ar tend to build up significant concentrations around the sorbent material, thus creating a diffusive barrier to further adsorption of CO_2. In order to prevent this diffusive barrier of non-CO_2 gases from forming, a small blower has been incorporated into the design to centinually circulate fresh Martian atmosphere through the sorbent bed. As the incoming Martian atmosphere enters the sorption compressor, the residual permanent gases are displaced and the diffusive barrier is eliminated.

Since the adsorption compressor is designed to extract 3.08 kg of CO_2 from 3.24 kg of Martian atmosphere (95% CO_2), 0.162 kg of residual gases must be displaced during the night adsorption period. To be conservative, the fan is sized to circulate three times this amount, or 0.486 kg of gas during a 9 hour night, or 0.015 g/s. This implies that the volumetric flow rate at 195 K and 6 torr is 4 I liters/min or 1.4 ft^3/min. Therefore, the selected fan must have sufficient power to drive this volumetric flow rate through the bed and must overcome the inherent pressure drop across the bed, valves, filters, and components.

Sorbent Bed Pressure Drop

The pressure drop through the sorbent bed is a critical factor in determining the required size and power of the circulating fan, as well as in determining the rate of CO_2 adsorption. Minimizing this pressure drop is highly desirable. Various design configurations were analytically modeled using the Ergun Equation for gas flow through packed beds, and results from this modeling were verified experimentally by low-pressure flow tests through various beds of sorbent pellets.

$$\frac{\Delta P}{L} = \frac{150\, V_o\, \mu\, (1-\varepsilon)^2}{D^2_{p\,eff.}\, \varepsilon^3} + \frac{1.75\, \rho\, V_o^2 (1-\varepsilon)}{D_{p\,eff.}\, \varepsilon^3} \qquad (1)$$

In general, the design parameters available for influencing pressure drop are bed length (L), flow cross-sectional area (Ac), and effective pellet diameter ($D_{p\,eff}$).

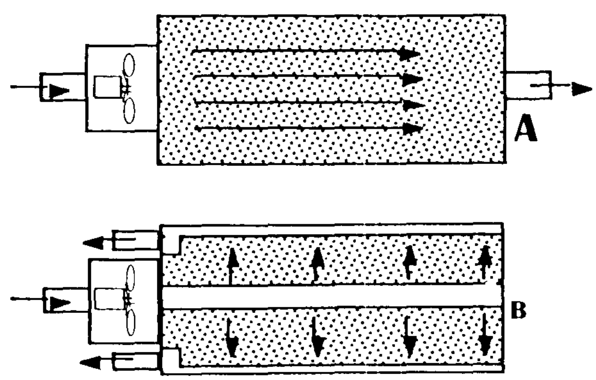


Figure 2. AlternativeJon configurations for the Mars adsorption compressor.

By adopting the design configuration "B" shown in Figure 2, the flow length is reduced by almost a factor of nine, while the cross-sectional area is relatively unchanged. For a fan flow rate of 0.0 I 5 g/s, configuration “A” yielded a pressure drop of 0.57 torr while configuration “B” was only 0.062 torr. In addition, by using 1/8” rather than 1/16” diameter sorbent pellets, the pressure drop could be reduced further down to 0.016 torr.

Experimental tests were run with a bed of zeolite pellets to confirm that the predictions of the Ergun equation are appropriate for such materials; good agreement with experimental results was obtained (see Figure 3).

Based on these analytical and empirical results, configuration “B” was selected for the design of the Mars adsorption compressor.

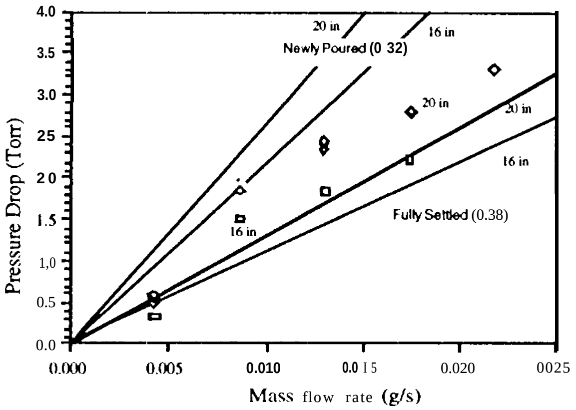


Figure 3. Pressure drop through a bed of zeolite at 6.5 torr. The lines are calculated from the Ergun equation. The two upper lines are for newly poured zeolite (void fraction -0. 32) and the two lower lines are for fully settled zeolite (void fraction -0. 38).

Valve & Component Sizing

Valves, lines and fittings must all be sized properly for the required flow rates of the sorption compressor. First, they must be large enough so that 3.24 kg of Martian atmosphere can be ingested by the sorbent bed during the Mars nighttime adsorption period. This results in an average flow rate for a 9 hour night of 0.10 g/s of Martian atmosphere. Superimposed on this flow rate, is the fan-induced flow rate for displacing residual permanent gases (0.0 I 5 g/s). Therefore, the total average flow rate is approximately O. 115 g/s of Martian atmosphere.

The minimum allowable valve size to accommodate this flow rate was determined analytically by treating the maximum gas flow through the valve as an isentropic compressible flow through an orifice. By determining the effective valve orifice diameter for which choked-flow begins, the minimum necessary valve orifice size was determined to be approximately 1 cm (Fig. 4).

The second aspect of valve sizing involves the pressure drop which the small circulating fan must overcome in order to continually displace the residual permanent gases collecting within the sorbent bed. Fortunately, it was determined that the 1 cm diameter minimum valve size determined previously for the high-capacity adsorption flow rate (O. 11 5 g/s) results in a pressure drop of only 0.06 torr for the low-capacity, fan-induced flow rate of 0.015 g/s.

Based on these analytical results, a minimum effective valve orifice diameter of 1 cm was baselined for the inlet and outlet valves of the sorbent bed.

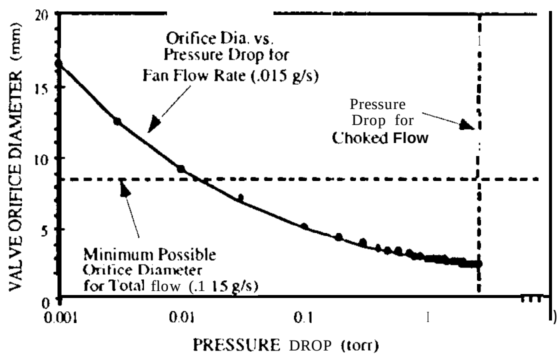


Figure 4. Required valve orifice size as a function of the desired pressure drop for a flow rate of 0.015 g/s.

Dust Filters

For an ISPP system to function effectively for an extended period of time on the Martian surface, dust control and mitigation is required. Of primary concern is the prevention of dust entering the sorption bed from the atmosphere.

A full-scale plant will ingest roughly 100,000 liters of Martian atmosphere per sol. Although some approximate estimates of dust distributions are available, the actual environment is likely to be highly variable with location, season, and dust storm activity. Based on a dust concentration estimate of 1 x 10”[9] g/cm), and the known daily atmospheric intake for the sorption compressor, the total dust ingested during 600 days of operation is estimated at 90 g.

Dust filtration on Mars is made difficult by the low ambient pressures, which require a low pressure drop across the filters. The pressure drop across a filter is a function of the velocity of the gas flowing through it, as well as the density or porosity of the filter. To reduce pressure drop, either the surface area or the porosity must be increased.

For the design of the sorption compressor, an advanced filter material from 3M known as "Filtrete" was selected. Unlike typical filters which basically trap particles larger than their openings, the Filtrete media is composed of a loose, open collection of permanently charged fibers. These charged fibers attract and hold the dust as the air passes by, capturing particles much smaller than the openings between the fibers. This allows the media not only to capture particles throughout the entire thickness of the media, but it also offers very minimal flow resistance, resulting in a low pressure drop across the system, even at fairly high face velocities.

Testing to measure pressure drop as a function of face velocity and dust loading showed that the pressure drop is only slightly dependent on the dust loading, but is linearly proportional to the face velocity (see Figure 5).

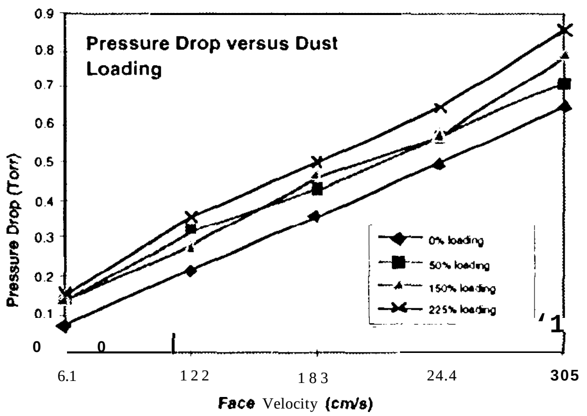


Figure 5. Filter material pressure drop test results,

Based on these results, it was found that 90 g of filter could easily handle 90 g of dust, and such a filter would have a frontal exposed area of 0.16 m^2. The pressure drop across this filter is estimated as 0.13 torr. By using a larger filter, the pressure drop can be reduced further.

Nighttime Cooling

To facilitate adsorption of CO_2 during the night, large quantities of heat must be removed from the sorbent material and rejected to the Mars environment overnight. Because the adsorption characteristics are highly dependent on temperature, the sorbent material must be cooled to as low of a temperature as possible during the night. A Iso, because the CO_2 adsorption process is exothennic, the heat of adsorption must be removed in addition to the sensible heat of the sorption compressor itself.

For cooling of the sorption compressor during the night, it would be highly desirable to thermally couple the sorbent bed directly to the cold Mars night-time environment. However, during day-time heating of the sorbent bed, it must be thermally isolated from the Mars environment to minimize heat loss. Given these requirements, the primary challenge for the thermal design of the adsorption compressor is to find an effective means of switching on and off this thermal link to the Mars environment.

Exposure of the adsorption bed to the environment can be accomplished by opening valves, but the flow rates will not be sufficient to cool the bed in the available time by blowing atmosphere through the bed.

By the end of daytime operation, the adsorption compressor is heated to an ultimate temperature of about 450 K. Therefore, the entire adsorbent bed must be cooled from 450 K to $\leq$ 200 K during the - 12 hr overnight period prior to initiation of the next day's heating cycle. The amount of heat that must be removed is the sum of the sensible heat for the sorbent material, container, filters, heater elements, etc., plus the heat of adsorption generated when the CO_2 is adsorbed.

Two approaches are under consideration for our design. One utilizes a solid conductor for heat transport at night with a thermal switch to interrupt the circuit during the day. This conductor must transmit an average of 183 W over a 12 hour period, A high conductivity strap with thermal conductivity 1000 W/m-K of cross sectional area 6 cm^2 coupled to a radiator of area - 1.0 to 1.5 m^2 would cool the bed to - 200 K overnight, depending on the night sky temperature (see Figure 6). This approach has the appeal of simplicity but it requires a reliable heat switch which will require a significant development effort.

The other approach consists of a small fluid pump and a closed loop of a tubing for circulating a heat transfer fluid from the adsorption bed to the radiator and back. During daytime heating of the sorbent bed, the fluid pump is not powered, the heat transfer fluid is not circulated, and no heat is carried from the sorbent bed to the radiator. However, during nighttime cooling of the sorbent bed, the fluid pump is powered on, the heat transfer fluid is continually circulated, and heat is removed from the sorbent bed and deposited at the radiator. The primary difficulty associated with this method is in finding an appropriate heat transfer fluid and a fluid pump that can operate reliably over a wide range of temperatures (170 K to 450 K). A heat transfer fluid such as Dow Syltherm XLT might suffice for this application. A flow rate of 2-3 g/s would suffice with a radiator of 1 m^2 to cool the bed to 200 K overnight.

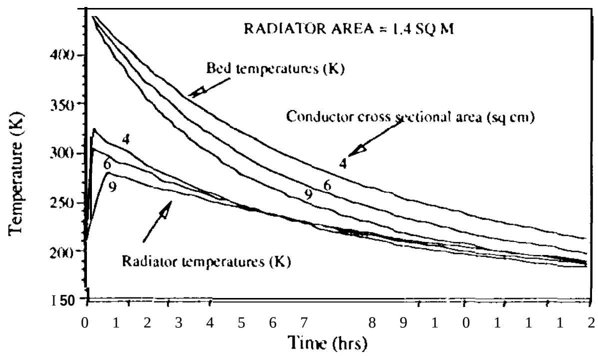


Figure 6. Radiator and sorbent bed temperatures vs. time for a radiator area of 1.4 m^2 for an effective sky brightness temperature of 145 K.

Daytime Heating

Heating of the adsorption bed begins in the morning after the sun rises and power becomes available. The initial electrical power that becomes available is used to pre-heat the reactor and the adsorption compressor prior to initiation of the conversion process. I'he first step is isolation of the adsorption bed from the environment by closing solenoid valves. Now if the adsorption bed is heated in this closed space, the pressure will rise. If the adsorption bed begins at say, 200 K, the temperature required to bring the pressure up to say, several hundred torr can be easily derived from Figure 1. To bring the pressure up to 100, 300 or 500 torr, requires heating the bed to 260 K, 310 K, or 325 K, respectively. As the day wears on and the reaction proceeds for hours, the adsorption bed will have to be continuously heated to replenish gas drawn off by the reactor. The data suggest that the rate of temperature rise will be roughly constant from -200 K to -400K because the separation of the isotherms appears roughly the same in this range. By late afternoon, the sorbent bed may reach -450 K, whereupon only 0.02 g CO_2 per g zeolite remain, and the zeolite is essentially depleted for all practical purposes (Point "C" in Fig. I).

To heat the adsorption bed in the morning from 200 K to say, 310 K, requires about 3 x 10^6 J. The profile of power availability will rise sharply in the early morning, and most of this power would be used to heat the adsorption bed. It will take about 400 W for two hours to bring the adsorption bed up to temperature. For the rest of the day, we must supply enough heat to bring the bed up from 310 K to 450 K plus the heat of resorption. Over a period of say, seven hours, this requires a continuous power input of about 200 W. Some of this may be recoverable from waste heat from the reactor.

Sorbent Bed Design

The adsorption pump design is in the form of a canister with the following characteristics:

Length	36 in
Diameter	10 in
Volume	42 liters
Sorbent Mass	27 kg

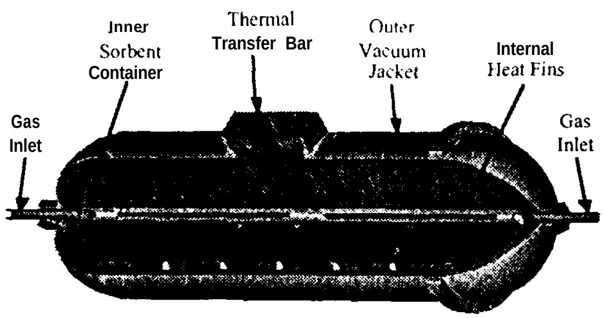


Figure 7. Adsorption pump design

An inner chamber contains a network of fins in which the zeolite sorbent is placed, with a thermal transfer bar for transferring heat from the sorbent bed to an external radiator at night. An outer chamber is separated from the inner chamber by a vacuum jacket to minimize heat loss, and inlets are provided at either end. Flow is down the center tube and radially outward through the bed (see Figure 7). A small fan is used to gently circulate gases to prevent build-up of non-adsorbed permanent gases such as Ar and N_2.

The entire sorption pump assembly is illustrated below in Figures 8 - 13. The sorption bed is mounted horizontally below a radiator which faces upward to the night sky. I'he connection between the two is via a thermal transfer bar. A heat switch is provided which can interrupt the transfer of heat to the radiator during daytime pressurization. Alternatively, it may be desirable to use a pumped liquid loop to transfer heat from the sorption bed to the radiator. The filter is divided into two pieces with one piece serving to remove dust from the inlet to the fan and the other serving to prevent dust entry into the "air" exit port.

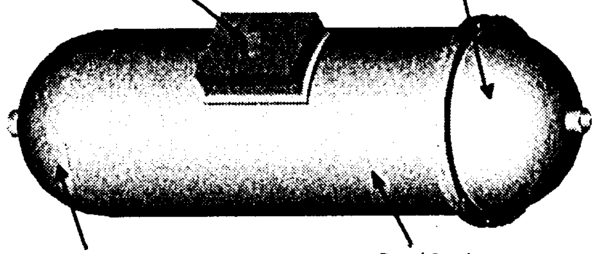


Figure 8. Outer vacuum jacket.

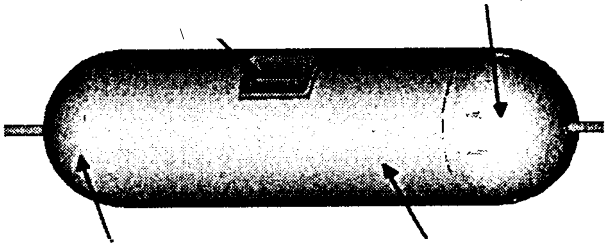


Figure 9. Inner sorbent container.

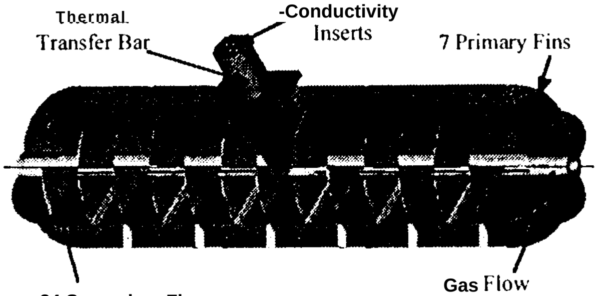


Figure 10. Internal heat fin structure

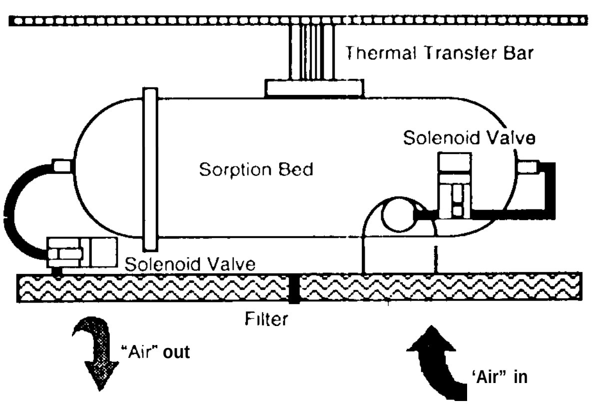


Figure 11. Sorption Pump Assembly

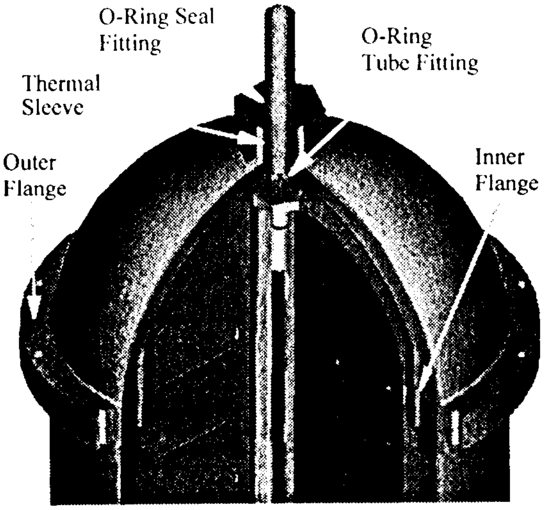


Figure 12. Flanged dome

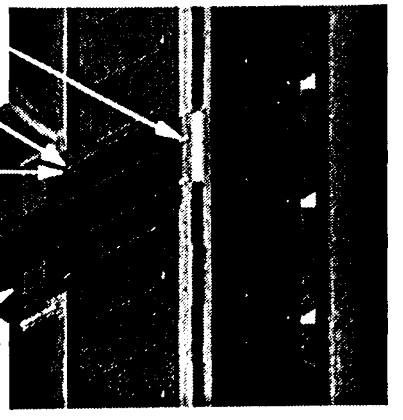


Figure 13. Interface of thermal transfer bar with sorption tank

Insulation

Since the primary source of energy used to generate pressurized CO_2 comes from scarce solar energy, every effort must be made to preserve this resource. Very efficient insulation must be used to prevent heat loss to the environment. With internal sorbent temperatures as high as 450 K, the insulation system must withstand large temperature excursions.

Batt-type insulation will be used for any system as the outer protection from the environment. Unfortunately, modeling shows that heat losses through reasonable amounts of batt-type insulation are excessive. Therefore we have included a vacuum jacket for the sorption pump with reflective layers to reduce heat losses. This high-temperature MLI approach greatly reduces losses, although at some cost in weight and complexity (see Figure 14).

Sorbent Bed Performance Modeling

The temperatures for a single fin section inside the sorbent bed during the heating and cooling cycles were calculated using a comprehensive 60-node, 110-conductor SINAPS-SINDA/FLUINT thermal model. For an assumed night sky temperature of 170 K and a 1 m^2 radiator, sample results are shown in Figure 15. A colder night sky and/or a larger radiator will cool the bed to lower temperatures overnight.

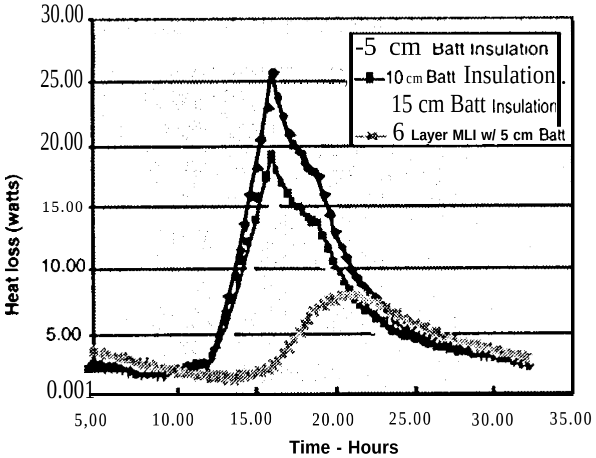


Figure 14. /lest Losses Through Insulation

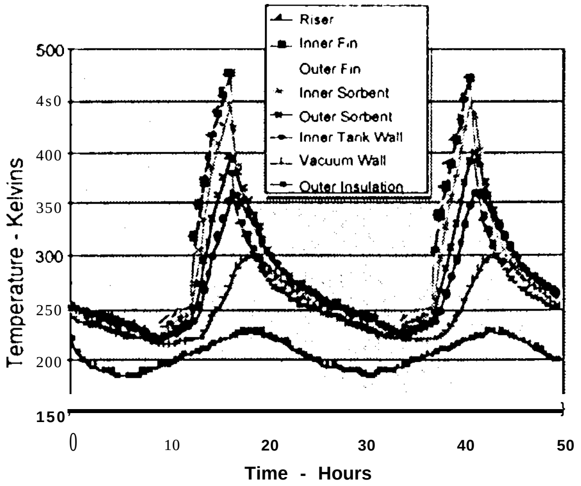


Figure 1.5. Diurnal variation of temperatures

conclusions

In order to justify inclusion of any ISPP system in future Mars Sample Return or human exploration (HEDS) missions, this technology must clearly demonstrate (1) the highest levels of reliable, robust operation and (2) mission-level mass savings worthy of the additional complexity and risk. By taking the various ISPP technologies, such as the CO_2 adsorption compressor, from the level of breadboard demos to flight-like hardware, it is hoped that much of the uncertainty associated with this technology can be eliminated and that the potential risk to future missions can be greatly reduced.

References

1. D. L. Clark, et al., "ISPP Demonstration," Final Report, JPL Contract 960247, Lockheed-Martin Astronautics, Denver, CO, April 3, 1996.

2. C. P. McKay, T. R. Meyer, P. J. Boston, M. Nelson, T. MacCallum, and O. Gwynne, "Utilizing Martian Resources for Life Support," in Resources of Near-Earth Space, edited by J. S. Lewis, M. S. Matthews and M. Guerrieri, Univ. of Arizona Press, Tucson, 1993, pp. 819-843.

3. C. G. Justus, B. F. James and D. L. Johnson, "Mars Global Reference Atmospheric Model (Mars-GRAM 3.34): Programmer's Guide," NASA Technical Memorandum 108509, May, 1996.

4. Private communication of extensive measurements of isotherms for adsorption of carbon dioxide on zeolites from Dr. David Quinn, Department of Chemistry and

Chemical Engineering, Royal Military College of Canada, Kingston, Ontario K7K 5L0.

5. J. E. Finn, C. P. McKay and K. R. Sridhar, “Martian Atmospheric Utilization by Temperature-Swing Adsorption,” 26th SAE Int'l Conf. on Environmental Systems, Monterey, CA, July 8-l I, 1996.

6. UOP/Union Carbide Technical Data Sheets, UOP Molecular Sieve Division, 120 Eglington Ave., East, Suite 304, Toronto, Canada M4P 1 E2.