The Impacts of Cabin Atmosphere Quality Standards and Control Loads on Atmosphere Revitalization Process Design

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Jay Perry

NASA, Marshall Space Flight Center

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Introduction

Atmosphere revitalization functions include:

- Carbon dioxide removal
- Trace contaminant control
- Particulate and debris removal

Standards defined by:

- NASA-STD-3001 Vol. 2

Supplemented by:

- NASA/SP-2010-3407 Rev. 1 (2014)
- Relevant literature

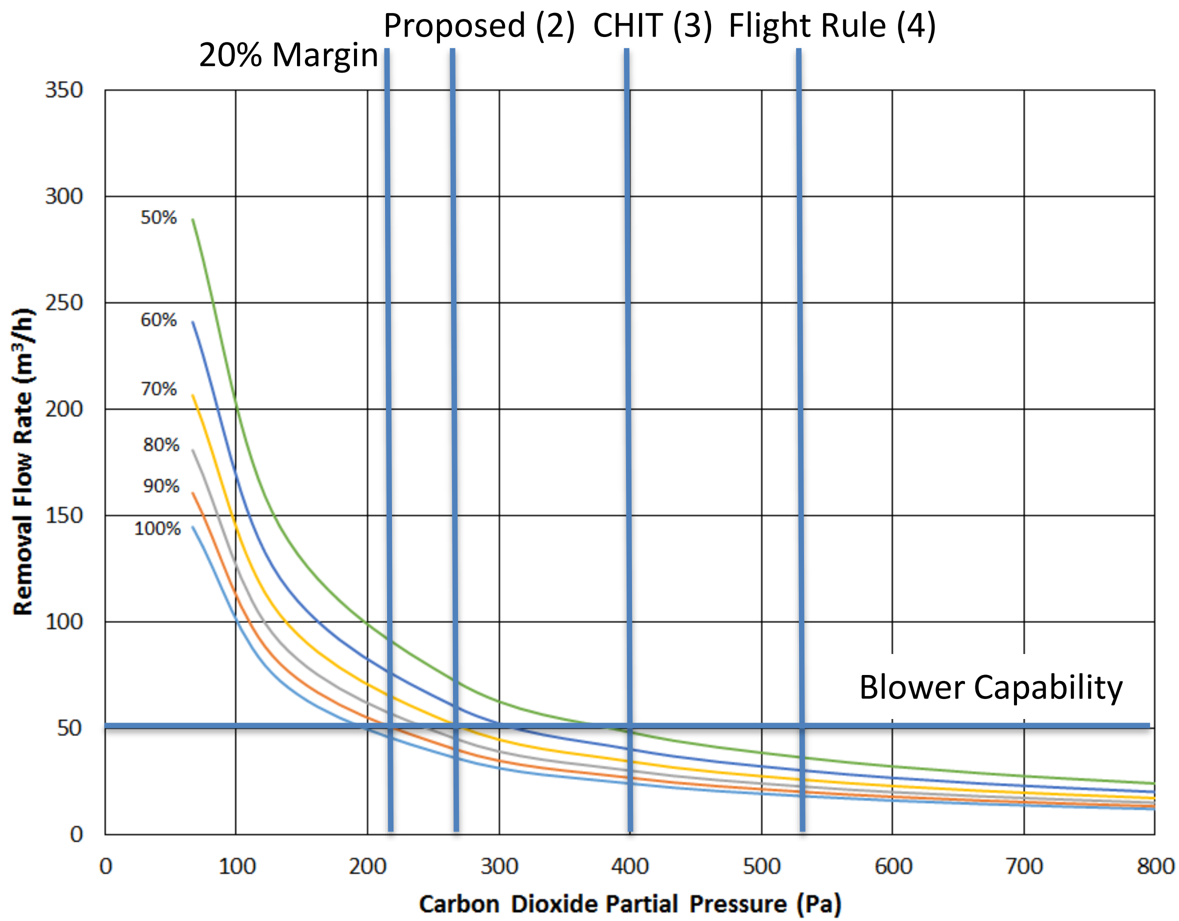
The Material Balance

Basis	*Equation*	*Steady State*
Mass:	${dm}/{dt} = r_i - \left({\eta\dot{v}}/{V}\right) m$	$m = {r_i V}/{\eta\dot{v}}$
Concentration:	${dC}/{dt} = {r_i}/{V} - \left({\eta\dot{v}}/{V}\right) C$	$C = {r_i}/{\eta\dot{v}}$
Pressure:	${dp}/{dt} = \left({RT}/{MV}\right) r_i - \left({\eta\dot{v}}/{V}\right) p$	$p = \left({RT}/{M}\right)\left({r_i}/{\eta\dot{v}}\right)$

Effective flow = Load/Control standard

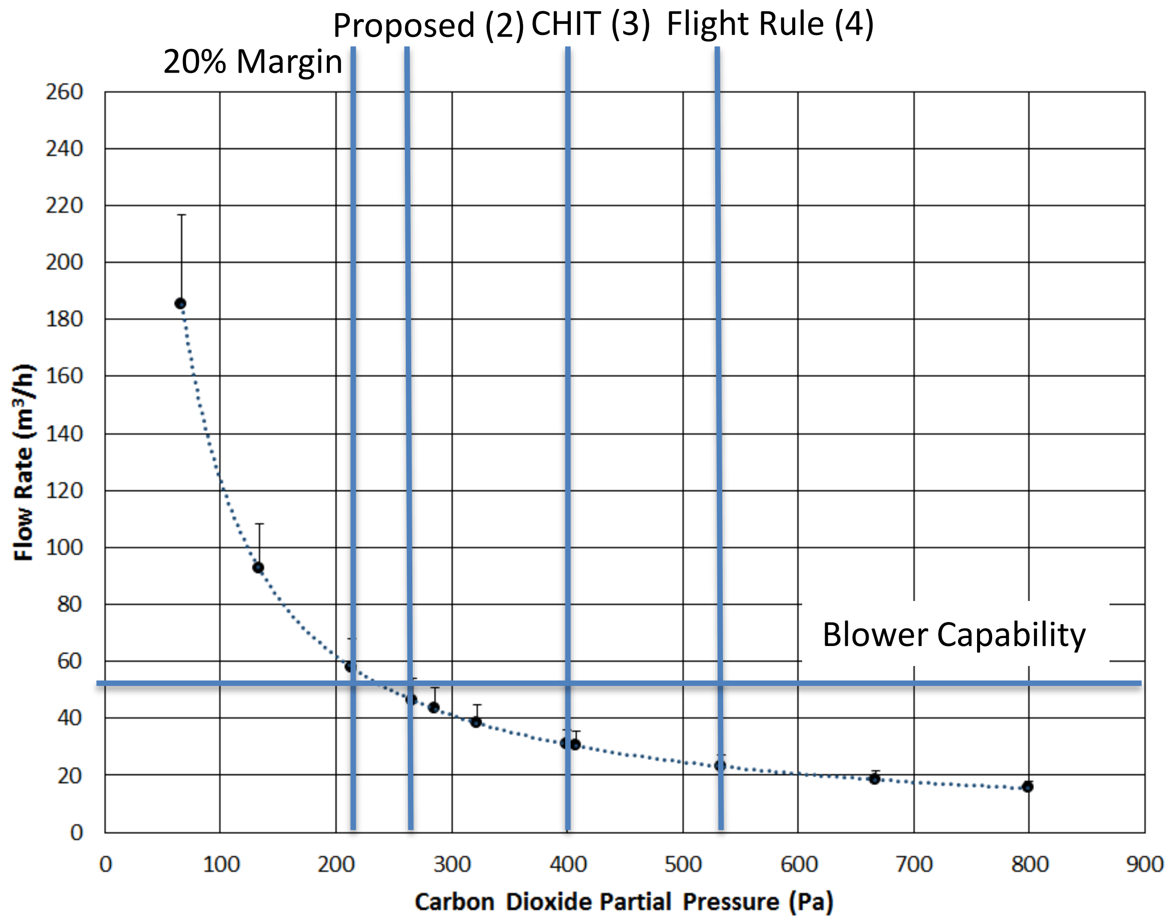
Carbon Dioxide – Part 1

- More challenging control standard for exploration.
- Effective flow increases rapidly for control standards <300 Pa.
- Flow for proposed standard with 20% margin is 150% higher than the ISS flight rule level and 88% higher than the CHIT level.



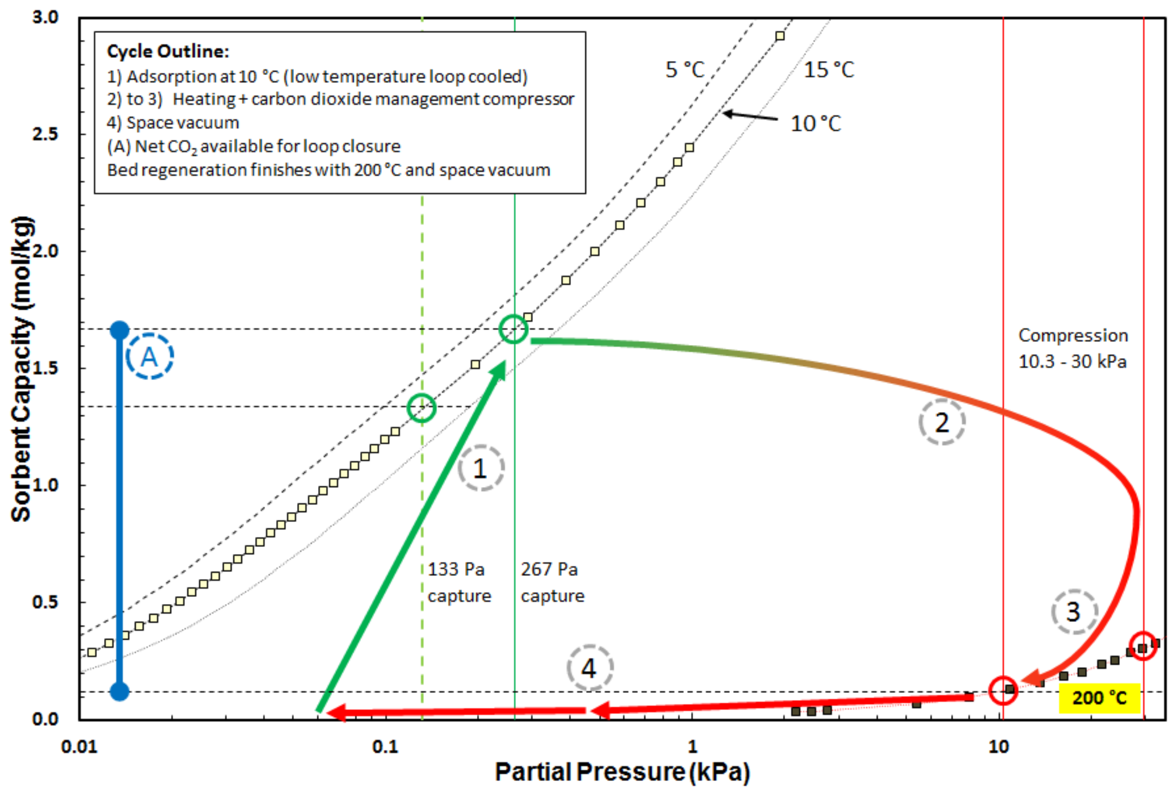
Carbon Dioxide – Part 2

- Flow margin is added to accommodate load variability.
- Exercise protocols and crew physical size.
- Up to 17% flow margin on top of the control standard impacts.
- Power growth at 213 Pa control standard is 62% higher than for 400 Pa control standard.



Carbon Dioxide – Part 3

- Lower carbon dioxide partial pressure reduces working capacity.
- With no other compensation or system growth, 33% loss in available carbon dioxide for reduction processes may result.



Courtesy Greg Cmarik.

Trace Contaminant Control

- Load source impacts lead to flow rate and size growth.
  - Urine distillation vent gases: 0.1 mg/h non-methane VOCs (<1%)
  - Heat melt trash compaction: 118 mg/h non-methane VOCS (4X flow)
  - Water recovery from urine distillation brine: 38 mg/h non-methane VOCs (2X flow)
- Impacts from maximum allowable concentration updates.
  - Design flow rate driver decreased from 7 mg/m^3 to 2 mg/m^3 (71% decrease)
  - Load decrease of 85% offset the maximum allowable concentration change.
- Maximum allowable concentration implementation.
  - Incorporating toxic hazard index increases flow by up to a factor of 2.4.

$$\eta \dot{v} = \left({}^{1}/_{T_H} \right) \sum {}^{r_i}/_{C_{max}}$$

Particulate Matter Control

- Control standard in NASA-STD-3001 Vol. 2 is 80 times less challenging than that used by the ISS Program.
    - ISS Program based the design requirement on Class 100K cleanroom.
        - <0.05 mg/m^3 for the size range 0.5 µm to 100 µm.
    - NASA-STD-3001 Vol. 2 is based on human health effects.
        - <1 mg/m^3 for the size range 0.5 µm to 10 µm; <3 mg/m^3 for the size range 10 µm to 100 µm
- Particle generation load considerations.
    - Literature review indicates particulate generation to be ~4 times higher than used for design by the ISS Program: 1.33 mg/minute-person vs. 0.31 mg/minute-person.
    - Flow required to comply with the NASA-STD-3001 Vol. 2 standard is 93% lower than to meet the ISS requirement for the increased load.
- Bioburden generation load considerations.
    - Load defined as 204 bacteria-related particles/minute-person and 53 fungal-related particles/minute-person.
    - Requires 22% higher flow than controlling the basic particle generation load.
- Surface dust intrusion considerations.
    - Lunar dust <0.3 mg/m^3 for the size range <10 µm.
    - Dust intrusion barriers and methods must be >99.6% effective to avoid substantial filtration flow rate increases.

Conclusion

- Changes to carbon dioxide control standards and loads:
  - Controlling to <267 Pa requires 88% higher flow than for <400 Pa.
  - Compensating for lower removal efficiency requires an additional 5% flow increase.
  - Higher load requires an additional 17% flow rate margin.
  - Up to 71 m^3/h flow may be needed compared to 31 m^3/h (129% increase).
  - Power required may increase by 62% over state-of-the-art equipment.
  - Up to 33% loss in working capacity may make oxygen recovery from carbon dioxide more challenging.
- Changes to trace contaminant control standards and loads:
  - Changes to trace contaminant control standards and design-driving load have offsetting impacts.
  - Adding new processes with contaminant loads may require trace contaminant control flow increases up to a factor of 4.
  - Incorporating toxic hazard index can increase the required flow by a factor of 2.4.
- Changes to particle filtration standards and load:
  - Changes to the design standard and loads have offsetting impacts.
  - The bioburden is the primary design driver for particle filtration (with no surface dust intrusion) and provides 22% functional margin for controlling the general particle generation load.
  - Surface dust intrusion is the greatest technical challenge and must employ barriers and operational controls that are >99% effective to minimize impacts to cabin filtration system design.

Acknowledgments

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