CO2 Scrubber Design for 1ATM PSUB Life Support

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CO2 Scrubber Design for 1ATM PSUB Life Support

- Not as complicated to construct or use as re-breathers are for scuba.
  - water infiltration of scrubber
  - caustic cocktail
  - oxygen PO2 at 1atm not as critical as PO2 at scuba depth
- Scrubber is only one part of a multi-part system that MUST work correctly
- Monitoring of environment is critical

CO2 Scrubber Design for 1ATM PSUB Life Support

Design Considerations

- Understanding Respiration
- Scrubber Canister Design
- What size scrubber do I need?
- Replacing O2
- Atmospheric monitoring
- ExtendAir by Micropore Inc.

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Understanding Respiration

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Understanding Respiration

- **Tidal lung volume**
  Amount of air taken into the lungs in a single breath. (0.5 liters in an average adult)
- **Vital capacity**
  Maximum amount of air you can exhale after you inhale as deeply as possible.
- **Residual volume**
  Amount of air that remains in your lungs after you have completely exhaled.

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Understanding Respiration

- Sea level atmosphere contains
  - 21% O2
  - .037% CO2
- Body metabolizes O2 and produces CO2
  - Balancing act – need to maintain O2, clean CO2, but keep pressure in cabin at 1ATM
  - Cleaning CO2 without adding O2 will lower cabin pressure
  - Adding too much O2 will increase cabin pressure – possible oxygen toxicity.
  - DO NOT ADD AIR – ONLY Oxygen

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Understanding Respiration

- Need to maintain 21% O2 in 1ATM sub
  - Some upward flexibility exists in 1ATM cabin.
- Need to limit CO2 exposure in 1ATM sub
  - OSHA considers buildings with 800-1000ppm CO2 to have poor ventilation.
  - OSHA industrial exposure allows 5000ppm CO2 for 8 hours
  - Shuttle missions aborted if cabin reaches 20,000ppm (2%)
- Need to maintain 1ATM pressure within cabin
  - Higher pressures raise oxygen toxicity and decompression issues.

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Scrubber Canister Design

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Scrubber Canister Design

- Ensure that the gas is exposed to enough surface area of the absorbent to remove the CO_2.
- Ensure that the gas flow rates are slow enough for the CO_2 to be absorbed, this is known as the dwell time.
- Allow simple and correct packing of the absorbent material to avoid a path being formed that allows the gas to miss the correct path through the material, this is known as channeling.
- Prevent excessive moisture from reaching the adsorbent material.

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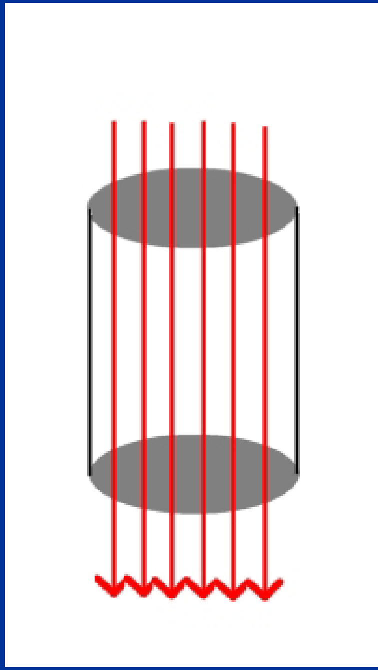
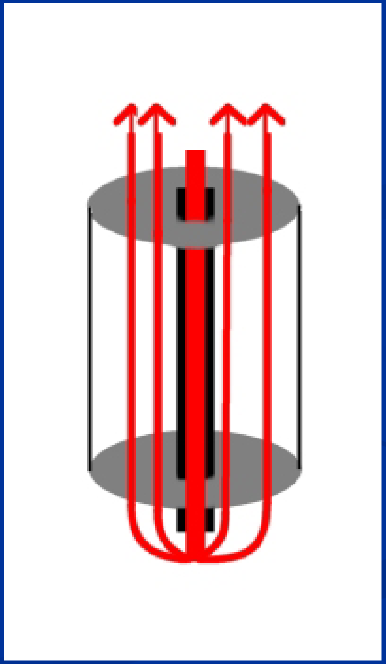
Scrubber Canister Design

- Axial Flow Scrubbers – air flows linearly through absorbent





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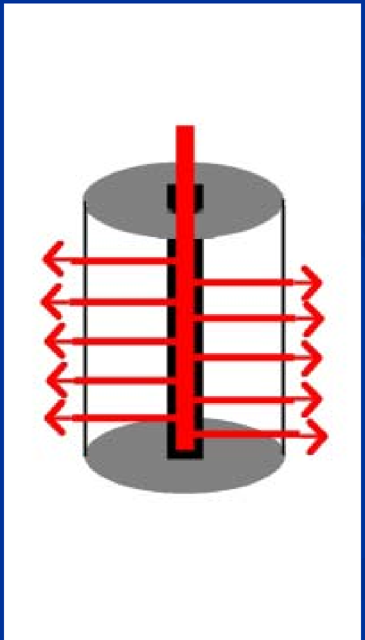
Scrubber Canister Design

- Radial Flow Scrubbers – air flows cross ward through absorbent from middle to outer side, or vice versa



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Scrubber Canister Design

- Flow rate of cabin air through scrubber canister
  - Sofnolime recommends a minimum of ½ second contact with non-exhausted material.
  - Consider premature failure due to inadequate dwell time caused by progressive chemical saturation.

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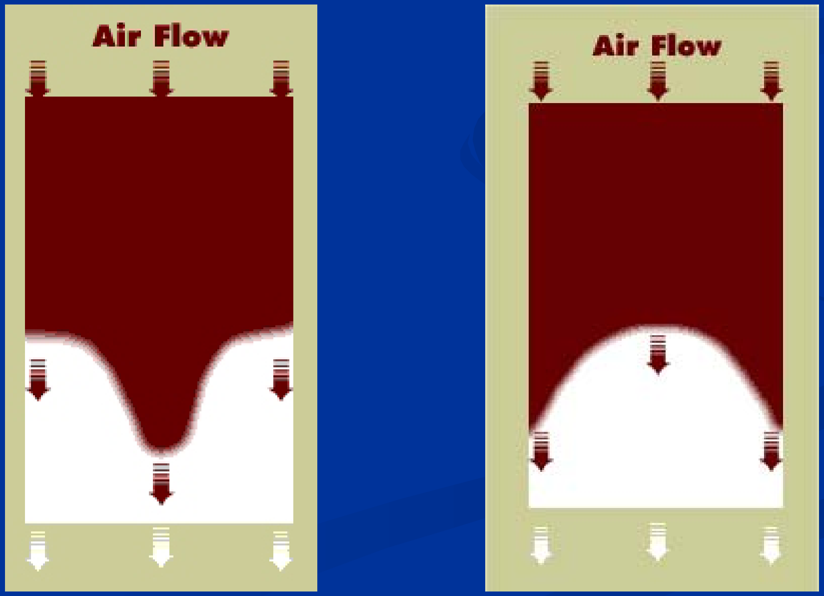
Scrubber Canister Design

- Channeling Inefficiency
  - Non-uniform gas flow through the canister causes most of the gas to follow the same path through only part of the absorber.



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Scrubber Canister Design

- By-Products of CO_2 absorption
  - Heat - up to 130 degrees F
    - Use proper canister materials
    - Heated air from canister may cause condensation issues in cabin
  - Water
    - Too much water will turn SodaSorb and Sofnolime to mush and reduce the efficiency of the scrubber
    - Insulate canister to help prevent condensation of air inside canister

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Scrubber Canister Design

- Basic Components
  - Diffuser – helps prevent channeling through canister.
  - Air filter or fine mesh to help control absorbent dust.
  - Canister of sufficient size to provide required dive time.
  - Low velocity fan or blower to circulate cabin air through scrubber.

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Scrubber Canister Design

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Scrubber Canister Design

- Basic Components
  - Low velocity fan or blower to circulate cabin air through scrubber.
    - Low power (12 v) computer fan should provide adequate air flow either directly attached to scrubber or via ducting to scrubber.

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Scrubber Canister Design

- Detecting CO2 absorbent exhaustion
  - Use clear canister and indicator chemical. Chemical changes color as absorbent becomes saturated with CO2.
  - Use temperature sensor on canister. Absorbent heats up as CO2 is captured and cools down when chemical is exhausted.
  - Calculate dive time using absorbent specifications and design parameters of your scrubber canister (volume, channeling, efficiency).

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Scrubber Canister Design

- Chemicals
  - SodaSorb – W. R. Grace Co., USA
    - 37 lb tub - $91.10 (shipping included) – $2.46/lb
      http://www.diverssupplyinc.com
  - Sofnolime – Molecular Products Limited, UK
    - 44 lb tub - $140.00 (shipping included) - $3.18/lb
      http://www.diveriteexpress.com

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What Size Scrubber Do I Need?

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What size scrubber do I need?

- Calculate the tidal volume of your respiration at a rate you expect to occur while diving in your sub.
- Count your respiration at a rate you expect to occur while diving in your sub.
- CO_2 comprises 5% of air exhaled by the average person
- Maximum CO_2 capacity of Sofnolime is 100 liters per Kg (2.2 lbs)

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What size scrubber do I need?

- Hypothetical CASE STUDY (1 person-1ATM cabin)
- 20 breaths per minute
- .5 liter tidal air transfer per breath
- 20 x .5 = 10 liters air transfer per minute
- 10 x .05 = .5 liter CO_2 per minute
- 100 liters CO_2/Kg (2.2 lbs) = 100 / .5 =

  theoretical 200 minutes of CO_2 Scrubbing

  (assuming 100% efficiency of canister design)

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What size scrubber do I need?

- Give attention to scrubber efficiency
  - Be realistic…nobody has created a 100% efficient scrubber.
  - Consider calculations and specifications "best case" scenarios.
  - Build a reasonable safety factor into your calculations.
  - Overbuild if possible.
  - Test, test, test.

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Replacing O_2

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Replacing O2

- Metabolized O2 must be replaced
  - Replace O2 as close as possible to the rate metabolized by crew.
    - Demand Flow replenishment
    - Constant Flow replenishment
    - Manual Flow replenishment
    - Combination of above

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Replacing O2

- Demand Flow Replenishment
  - A demand valve is used to automatically replace O2 based upon pressure drop that occurs when CO2 is absorbed by the scrubber. (similar concept to scuba regulator)
    - Pilot inhales, metabolizes O2, creates CO2
    - Pilot exhales, CO2 enters cabin
    - CO2 enters scrubber and is absorbed creating a pressure drop
    - Demand valve on O2 tank senses pressure drop and adds O2
    - Equalization of cabin to pre-set demand valve pressure stops O2 flow

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Replacing O2

- Demand Flow Valve
  - Nuytco Research Limited
    - Uses bellows sealed at 14.7 psi to act as barometer.
    - Bellows is adjusted prior to dive, to just touch needle valve that operates to admit O2 supply.
    - As cabin pressure drops due to CO2 absorption, bellows expands and pushes needle valve open.
    - When cabin pressure equals bellows pressure, O2 valve closes.
    - http://www.psubs.org/designguide/lifesupport.pdf

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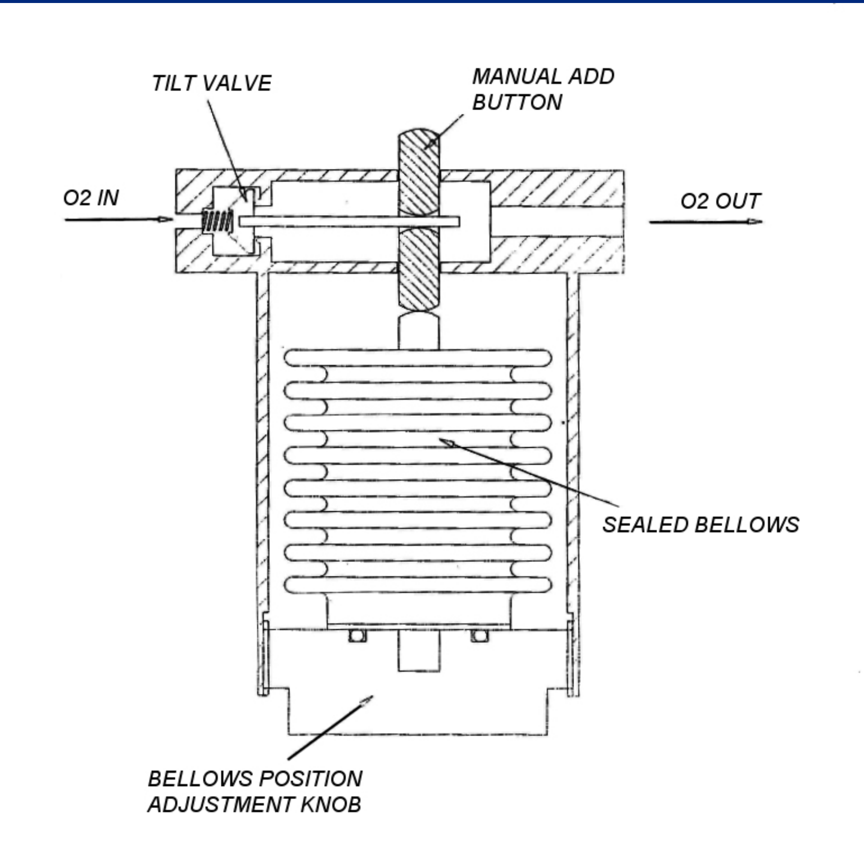
Replacing O2

Demand Flow Valve



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Replacing O2

- Constant Flow Replenishment
  - O2 tank manifold preset to deliver a metered amount of O2.
  - Replenishment calculated to match estimated metabolized O2 of crew.
  - Usually used in conjunction with manual replenishment option so that additional "bursts" of O2 can be added if activity of crew surpasses rate of metered replenishment.

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Replacing O2

- Manual Flow Replenishment
  - O2 replenished as pilot determines necessary by injecting O2 manually.
  - Monitor O2 meter and add when PPM becomes less than some pre-dive accepted value.
  - Distractions of piloting and/or observing make this the least desirable option.

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Atmospheric Monitors

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Atmospheric Monitors

- O2 Sensor – Shows the partial pressure of oxygen in cabin.
  - Critical piece of equipment to monitor life support.
  - OxyCheq (www.oxycheq.com) manufactures reasonably priced sensors.

Expedition $299.00

El Cheapo Kit $100

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Atmospheric Monitors

- CO2 Sensor – most units display concentration in PPM values.
  - Very expensive ($350-$1,500)
  - Most reliable method of determining when scrubber exhaustion has occurred.
  - Recommended equipment, however most re-breathers do not monitor CO2.

AirSense Model 310

$335.00

www.airspill.com

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Atmospheric Monitors

- Cabin Pressure Sensor – monitor rise and fall of interior cabin pressure.
  - Various types available - Altimeter, Barometer, Pressure Gauge.
  - Mostly inexpensive, accurate, and compact.
  - Monitoring cabin pressure is important
  - Adding too much replacement O2 will raise the ambient pressure in the cabin and could lead to oxygen toxicity and/or decompression issues.
  - Decreased cabin pressure could hamper end of dive operations (ie opening hatch)

CO2 Scrubber Design for 1ATM PSUB Life Support

ExtendAir by Micropore Inc.

www.extendair.com

CO2 Scrubber Design for 1ATM PSUB Life Support

ExtendAir by Micropore Inc.

- Pre-Manufactured Scrubber Cartridge
  - Uses Calcium Hydroxide instead of Sodium Hydroxide
  - Cartridge uses molded ribs to form channels for air flow
  - Controlled channels results in uniform air flow to absorbent
  - Absorbent and cartridge design is extremely efficient
  - Claimed to last 2-3 times longer than granular chemicals
  - Designed for re-breather retrofitting
  - Can it be utilized for PSUB 1ATM Life Support?

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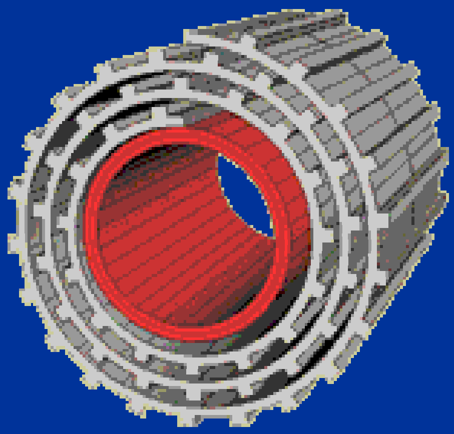
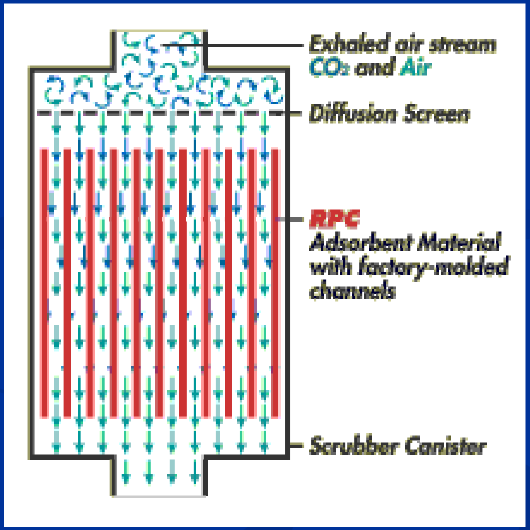
ExtendAir by Micropore Inc.

- ExtendAir Scrubber Cartridge





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ExtendAir by Micropore Inc.

- ExtendAir Re-Breather Retrofit Kits

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ExtendAir by Micropore Inc.

- PSUB 1ATM Retrofit Analysis
  - Can the ExtendAir re-breather kits be adapted for use in PSUBS?
  - Can the stock ExtendAir re-breather kits be modified to use fans for air flow through canister kit?
  - What about power failure? Adapter to allow mouthpiece?
  - Design a custom canister for ExtendAir cartridge use in 1ATM PSUBS?

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ExtendAir by Micropore Inc.

- ExtendAir Cartridge Benefits
  - Built-in efficiency not obtainable via home-built canisters.
  - Convenient packaging.
  - Sealed from atmosphere offering long term storage.
  - Easy to load in cabin just prior to dive.
  - Easier to unload after dive than granular canister design.
  - Reasonable cost for professionally designed scrubber (air flow, efficiency, etc)

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ExtendAir by Micropore Inc.

- ExtendAir Kits and Cartridges

Canister Kit

$329.00

Case of Four Cartridges

$119.80

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References

- www.webmd.com
- http://www.labour.gov.sk.ca/safety/mine-rescue-manual/chapter-1/mine-gases-2.htm
- http://www.labsafety.com/refinfo/printpage.htm?page=/refinfo/ezfacts/ezf230.htm
- http://www.molecularproducts.co.uk/v2/products/faqs.htm
- http://www.psubs.org
- Life Support in Small One-Atmosphere Underwater Work Systems – Dr. Phil Nuytten
- http://www.lakesidepress.com/pulmonary/books/scuba/gaspress.htm
- http://www.extendair.com
- Spacecraft Maximum Allowable Concentrations Volume 2, chapter B3