Analysis of CO_2 Scrubbers for the Plant Generic Bioprocessing Apparatus (PGBA)

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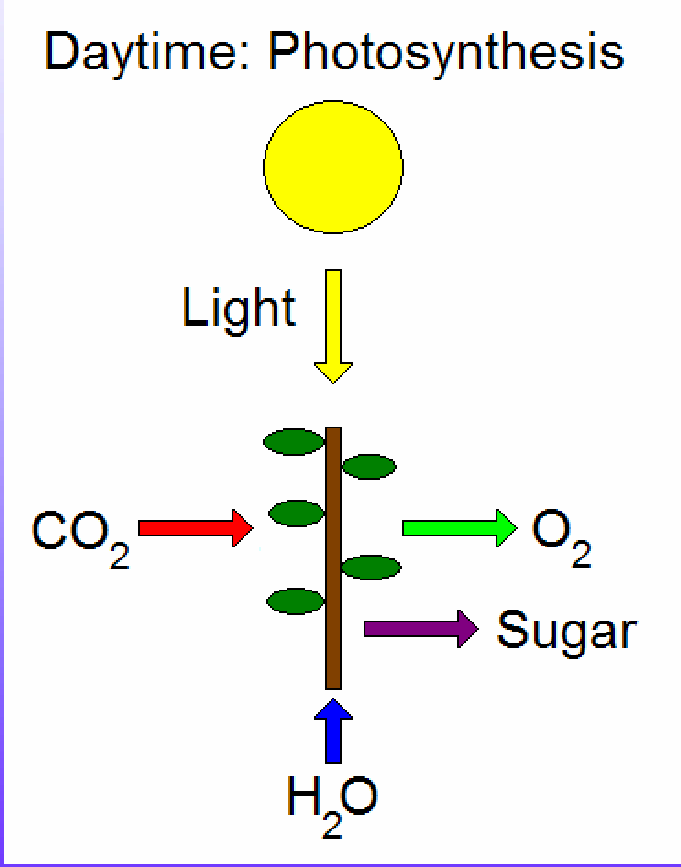
Space Payload Design

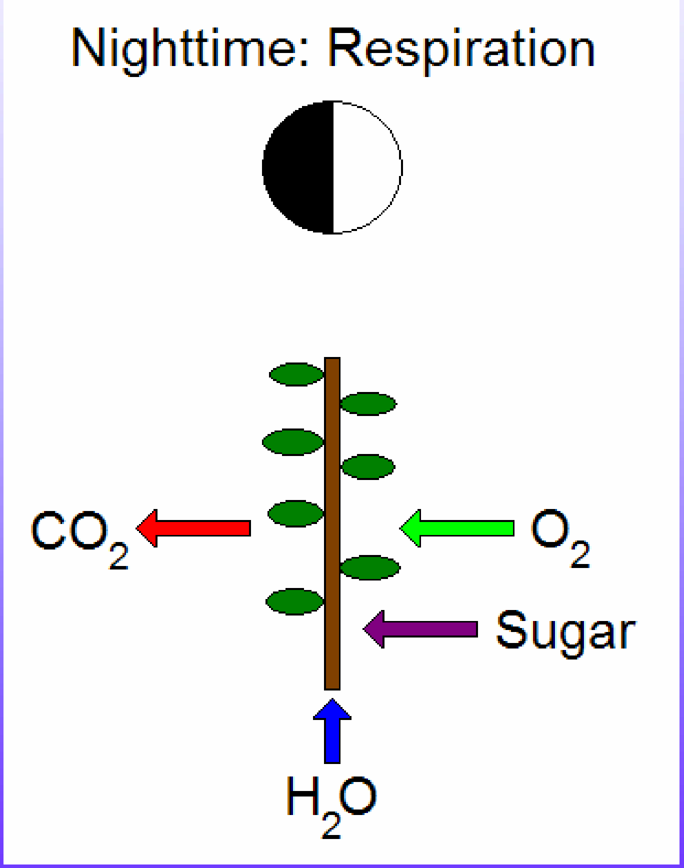
ASEN 5519

Plants: Daytime versus Nighttime



- During the day: Photosynthesis converts CO_2, Light and H_2O into O_2 and Sugar

Plants: Daytime versus Nighttime

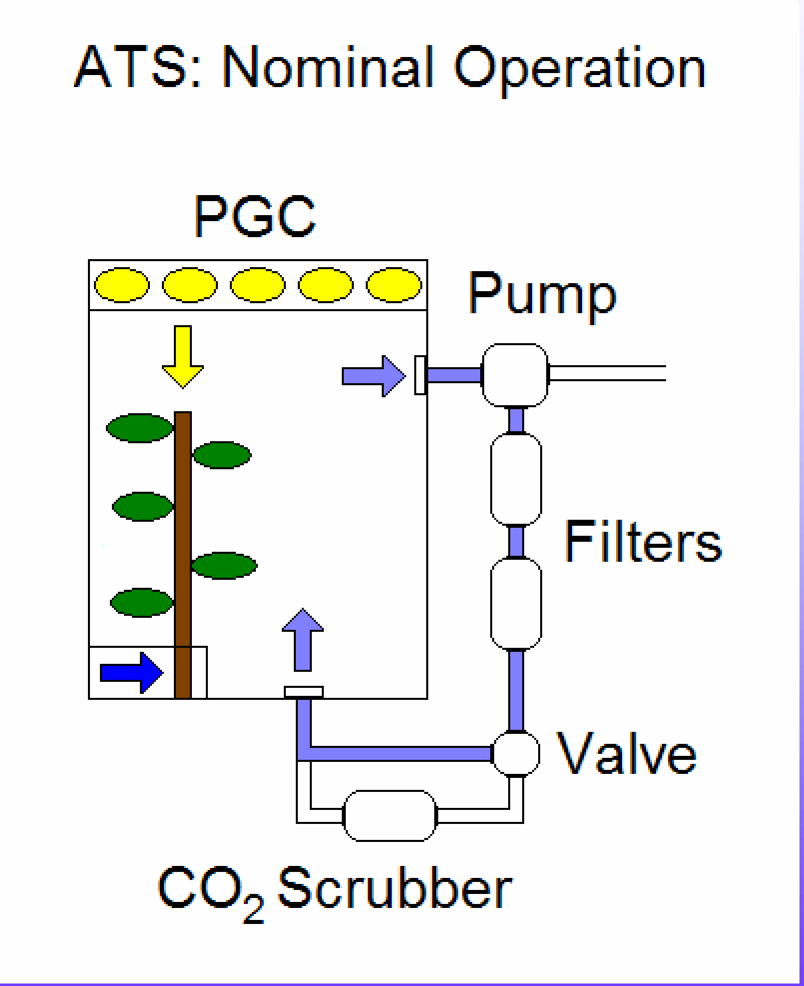


- During the night: Respiration converts O_2, H_2O and Sugar into CO_2 and plant growth

Plants in Space

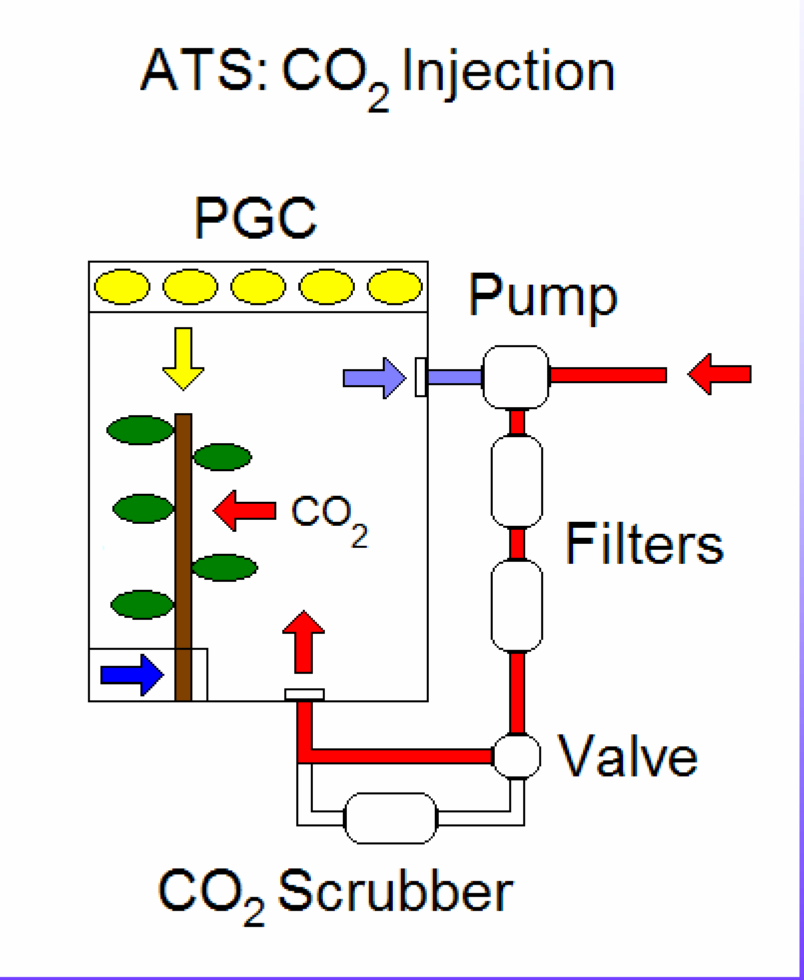
- Spaceflight requires that plants are kept in a Sealed Environment
- A Constant Level of CO_2 simplifies scientific analysis of plant growth
- Daytime: CO_2 injection to support photosynthesis
- Nighttime: Removal of respired CO_2 (Scrubbers)

PGBA: Atmospheric Control System (ATS)



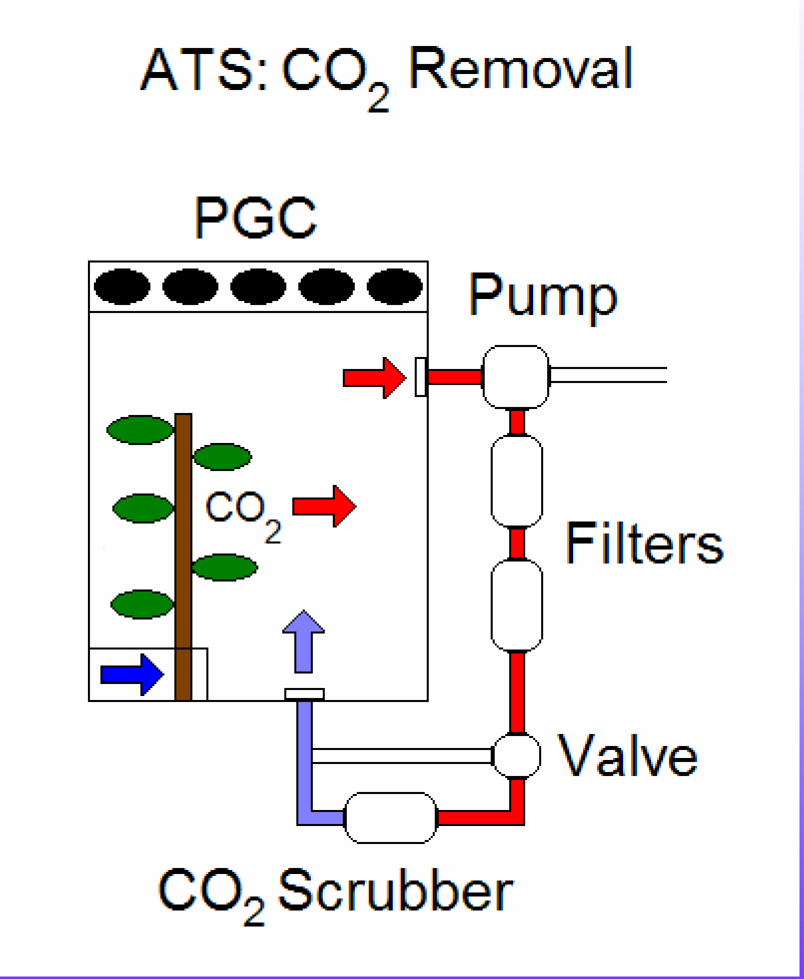
- Nominal:
- CO_2 within set parameters
- Plant growth chamber (PGC) air is internally circulated

PGBA: Atmospheric Control System (ATS)



- Daytime Photosynthesis:
- CO_2 bellow set parameter
- CO_2 rich cabin air is injected
- Cabin air acts as unlimited CO_2 source

PGBA: Atmospheric Control System (ATS)



- Nighttime Respiration:
- CO_2 above set parameters
- Internal air is diverted to CO_2 scrubber
- CO_2 chemically converted to H_2O vapor
- CO_2 removal is limited by amount and quality of scrubber

CO_2 Scrubbers

- Eight commercially available scrubbers were tested

1. Amsrob
2. Medisorb
3. Divesorb Dive Drager
4. Divesorb Pro
5. Dragersorb 400
6. Sodasorb
7. Sodalime
8. Baralyme

- These scrubbers are a mixtures of various hydroxides
- $Ca(OH)_2$,
- $Ba(OH)_2$,
- NaOH
- KOH

Chemical absorption of CO_2

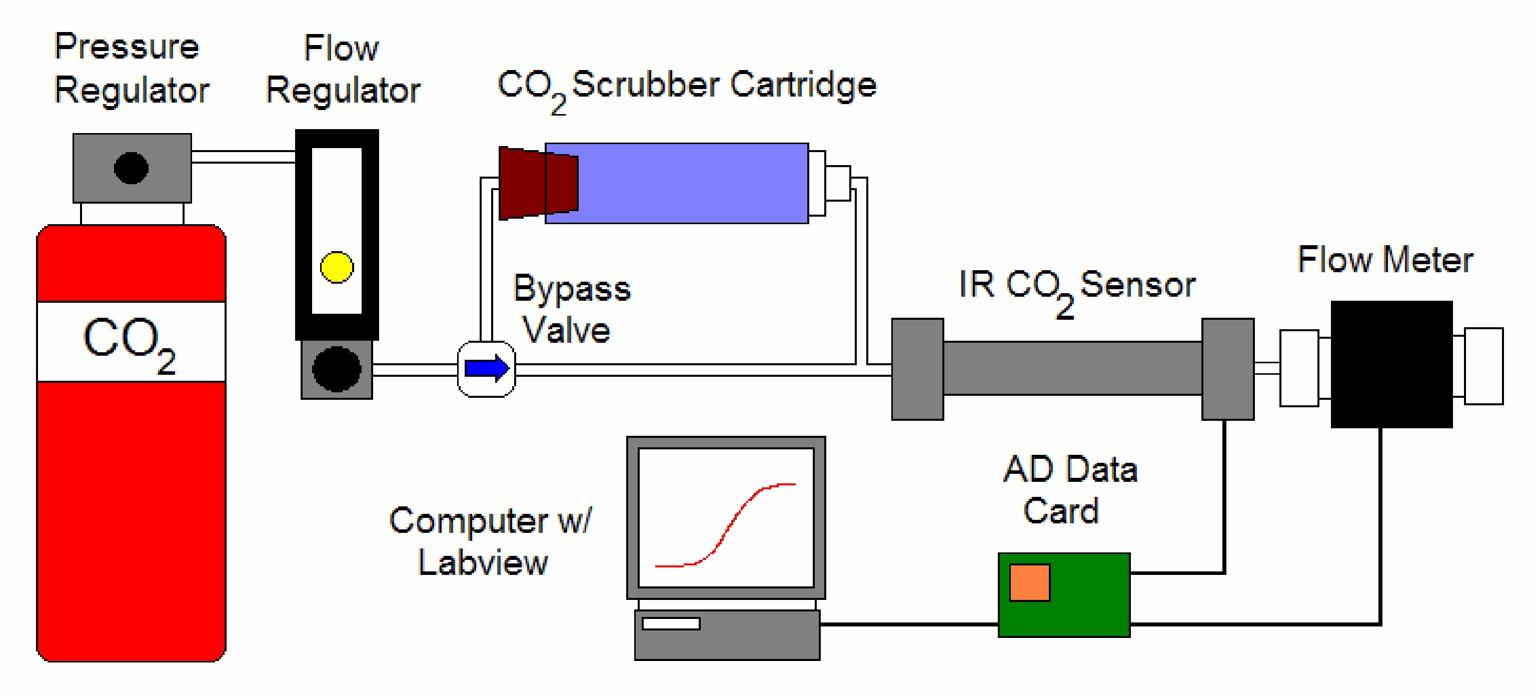
$$CO_2 + Ca(OH)_2 \rightarrow CaCO_3 + H_2O$$

Goals of Scrubber Analysis

- Identify the "best" scrubber
  - Highest ratio of absorbed to injected CO_2
  - Highest total mass of CO_2 absorbed
  - Longest "effective" operation time (> 33% absorption)
  - Highest packing density
  - Minimal dusting and breakup

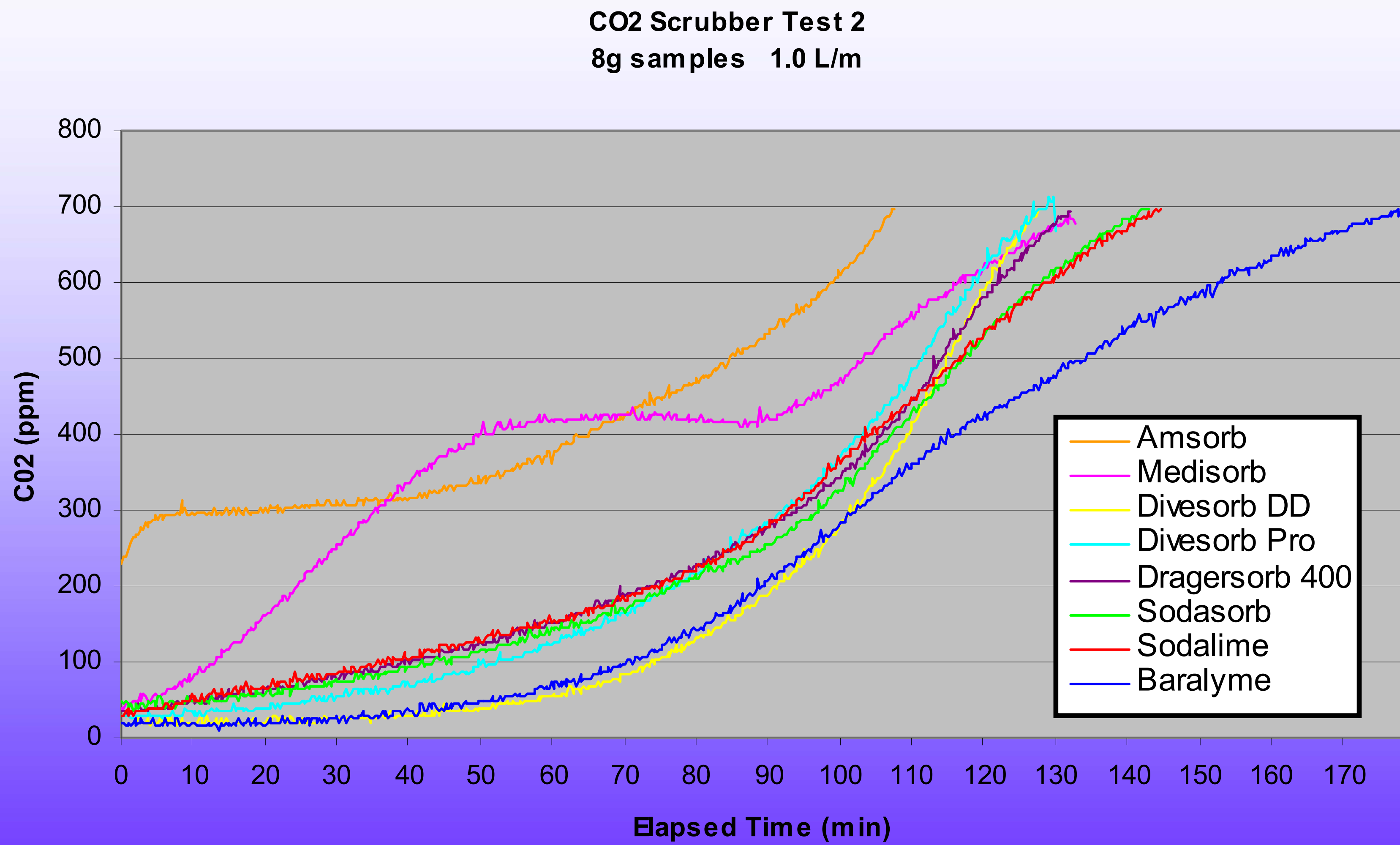
- Balance "realistic" experiment with feasible run time
  - 8 gram scrubber samples
  - 1.0 Liter per minute constant flow rate

Scrubber Experiment Setup



- Known CO_2 input concentration
- Control over CO_2 input pressure and flow rate
- Computer recorded flow rate and CO_2 output concentration
- Scaled down cartridge and flow rate to reduce run time

Experiment Data: Passed CO_2 vs. Time



Scrubber Performance Analysis

- Scrubber considered effective down to 33% CO_2 absorption
- The total mass of CO_2 injected was calculated using

$$m_{CO_2 total} = FR * T_{eff} * \rho_{CO_2}$$

- FR = flow rate, T_{eff} = time to reach 33% CO_2 absorption
- ρ_{CO_2} = density of CO_2 at 12.2psi (correcting for reduced atmos pressure)

- The total mass of CO_2 absorbed was calculated using

$$m_{CO_2 abs} = A_{int} * m_{CO_2 total}$$

- A_{int} = integrated area between 1000ppm and output CO_2 concentration

Scrubber Analysis Results

8g samples 1.0 L/m flow rate 33% Min. Absorption		Amsorb	Medisorb	Diversorb Dive Drager	Divesorb Pro	Dragersorb 400	Sodasorb	Sodalime	Baralyme
Ratio Absorbed to Injected CO_2		0.61	0.62	**0.85**	0.8	0.77	0.75	0.73	0.75
Total Mass of Absorbed CO_2 (g)		0.1045	0.1312	0.1734	0.1617	0.163	0.1739	0.1723	**0.2075**
Elapsed Time for 33% Absorption (min)		105.5	128.5	125.5	124.5	129	137.75	139.75	**170.5**
Packing Density (g/mL)		0.732	0.848	0.85	0.8	0.854	0.838	0.842	**0.892**
Cost ($/kg)		13.76	NA	NA	NA	4.75	**3.56**	7.33	10.26

- Baralyme was the best performer in three categories
- Lower absorbed to injected ratio resulted from long “tale” of low absorption

Future Work

- Add equipment to test for back pressure buildup
- Retest best performing scrubbers in a more realistic setup
  - Larger sample size
  - Higher flow rate
  - Longer test time
  - Full test in PGBA

Acknowledgements

- Dr. Alex Hoehn: Advisor
- Juniper Jairala: Researched and Purchased Scrubbers
- Hans Seelig: Labview Software
- Jeff Sweet & Anand Satyamoorthy: Hardware and Electronics

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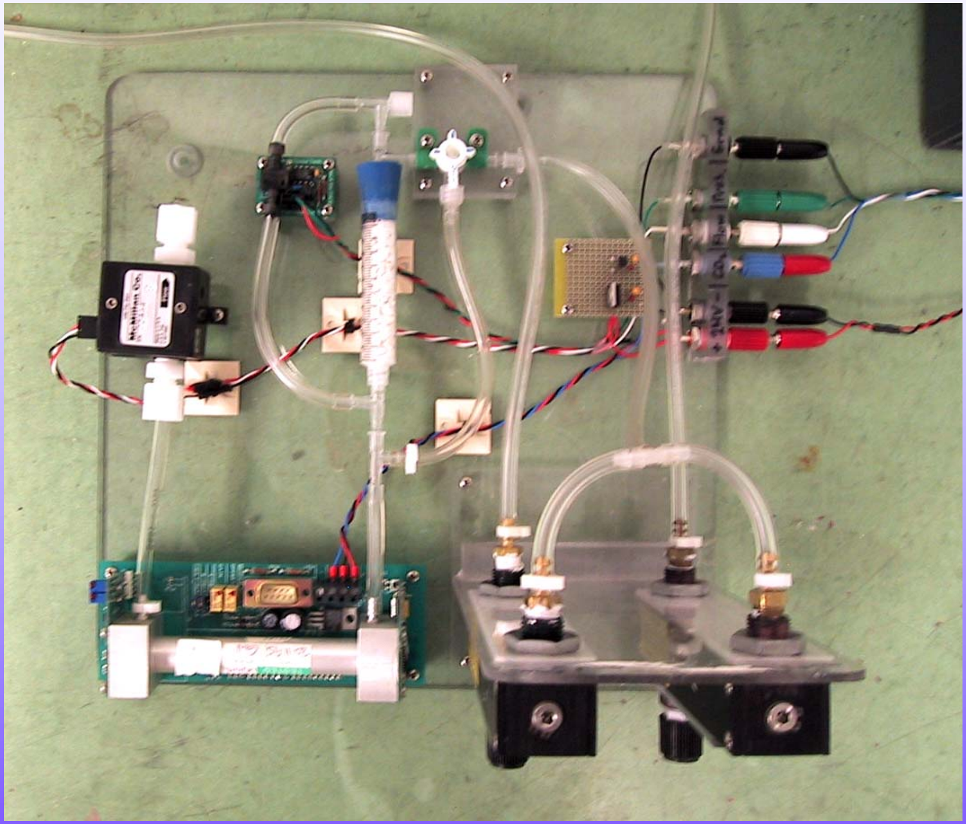
References: Experiment Procedures

1. A scrubber cartridge was weighed using a digital scale (including filters and rubber stopper)
2. 8 grams (+/- .01g) of scrubber was weighed out using a digital scale
3. The scrubber was loaded into the cartridge with filters at the entrance and exit points
4. The cartridge was loaded into the Scrubber Testing Apparatus as illustrated in Fig. 1
5. The valve was set to bypass the cartridge
6. The regulator on the 1000ppm CO_2 cylinder was set to 10 PSI injection pressure and flow was started
7. The N052 – 075T flow tube was used to adjust the flow rate to 1.0 L/m (This was checked using the analog output from the 100-7 flow meter with V_{out} = 2.46V)
8. The Labview VI was activated and began to record the analog outputs of the CO_2 transmitter and the flow meter.
9. The bypass valve was turned to direct flow into the scrubber cartridge
10. The flow rate was monitored and if necessary was adjusted to keep it constant a 1.0 L/m for the entire data collection period. (V_{out} = 2.46V +/- 0.05V)
11. The VI collected data until the scrubber was allowing 700 ppm CO_2 to pass through. (This ensured that the 33% absorption point of 666 ppm was reached)
12. Flow was stopped and the valve reset to bypass
13. The cartridge was removed and weighed
14. Steps 1 through 13 where repeated for each remaining scrubbers

References: Experiment Equipment

- Compressed Gas Cylinder of 1000ppm CO_2 balanced in Air (with regulator)
- Compressed Gas Cylinder of Nitrogen (with regulator)
- Cole-Palmer N052 – 075T flow tube (0.25 – 2.5 L/min)
- Scrubber cartridge (10 ml syringe with rubber stopper and two inline felt filters)
- Vaisala GMM12A CO_2 Transmitter
- McMillan Model 100-7 flow meter (0.4 – 2.0 L/m)
- HP 6215A Regulated Power Supply
- Voltage regulation electronics (24V input to 24V, 12V, 5V output)
- National Instruments data acquisition card
- Lab View Vi for analog data collection
- Three-way bypass valve
- Luer lock fittings
- 3mm tubing

References: Experiment Equipment



Picture of mounted testing apparatus