Producing Air Revitalization Sorbents from Spacecraft Waste Biomass

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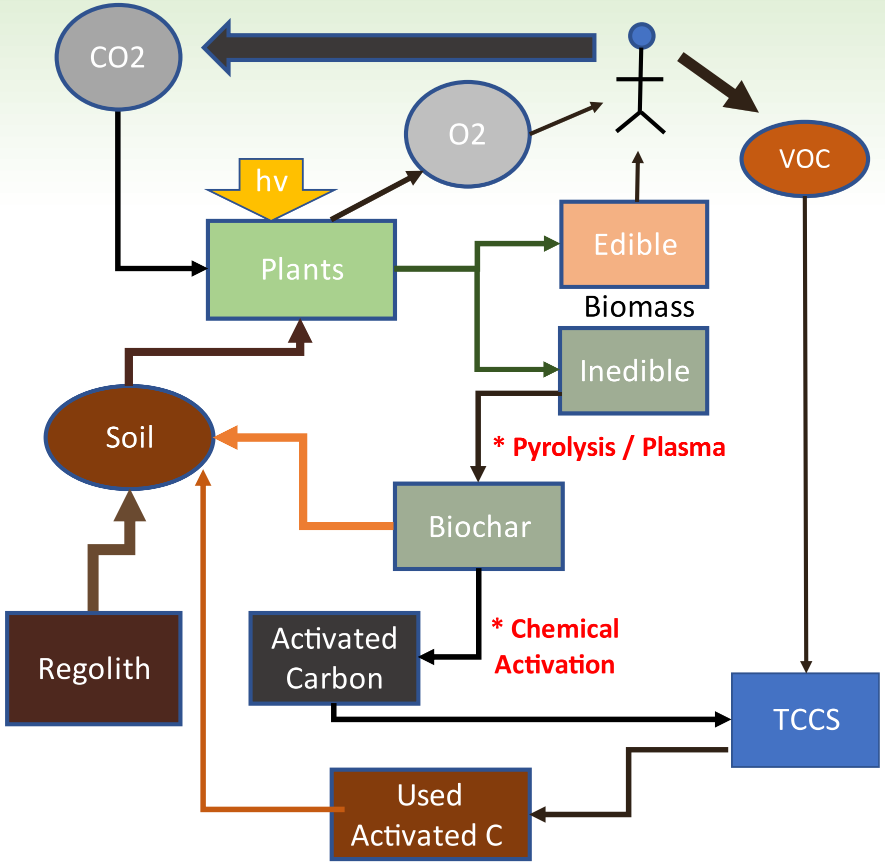
Bioregenerative Life Support

- Future long-term exploration missions on permanent bases on the moon or Mars require the development of Bioregenerative Life Support Systems (BLSS) with hybrid life support subsystems employing both physico-chemical (PC) and biological technologies to reduce the requirement for supplies from the Earth.
- Food systems for supporting exploration missions use crop production systems to produce fresh crops to supplement crew diets. In BLSS designs, plants also recycle water via transpiration, and produce O_2 and remove CO_2 from the atmosphere via photosynthesis (Figure 1). However, only 30-80% of all crops is edible biomass and the remainder 20-70% is inedible biomass that becomes waste unless it can be recycled.



Bioregenerative Life Support

- On Earth, biochar can help close the carbon loop by recycling inedible plant biomass or other C waste biomass that can be used as soil amendments. In space, biochar could be added to lunar or Martian regolith to improve their fertility.

- As mission duration and crew size increases, the logistics of resupply and disposal of ECLS consumables like activated carbon may become limiting. In this paper, we present simple PC methods to convert inedible plant materials, food waste, or bioreactor biomass into biochar. The biochar can be treated chemically and converted into activated carbon, which is then impregnated with phosphoric acid. The resulting impregnated activated carbon can be used in the Trace Contaminant Control System (TCCS) beds for air revitalization of crew cabin air. The SOA TCCS uses 50 lbs of impregnated activated C with 5-6 yrs of service life for crew of 6. Once spent, the TCCS carbon beds loaded with volatile organic carbons (VOCs) and NH3 salts can also be used as soil amendments for plant growth (Figure 1).
- The objectives of this study are two-fold: 1) produce impregnated activated C sorbents for TCC from C wastes, and 2) compare the VOC removal capacities from C waste derived sorbents with commercial impregnated activated carbons. The ability to produce suitable activated carbon in surface habitats would increase hybrid BLSS efficiency

Activated Carbon from Wastes

- The production of biochar from C wastes (inedible plant biomass, bioreactor sludge, and algal biomass) and its subsequent conversion to impregnated activated carbon could eliminate the need for resupplying impregnated activated carbon for the TCCS beds from Earth. In turn, the carbon from the used TCCS beds could be recycled as soil amendments for plant growth. Used TCCS carbon contains NH_3 salts that may help with plant nutrition and other adsorbed VOCs that would be degraded by the rootzone microbiome. This approach is feasible if the activated carbon produced from waste biomass has the same adsorptive capacities for VOCs (e.g., NH_3 and DCM) as the activated carbon it replaces. In addition, the processes for forming the biochar and activated carbon cannot be energy intensive, require large amounts of chemical consumables, or require additional hardware because of the mass, power, and volume limitations of spacecraft.

Activated Carbon from Wastes

- Activated carbon can be produced from C waste biomass in two steps: 1) biochar formation using slow pyrolysis, and 2) activation with chemical agents. In slow pyrolysis, dry biomass is heated in a reactor to 400-600°C for 1 hr in an oxygen-limited or deprived atmosphere6,7. Biochar from tomato biomass was produced at KSC by heating it in a kiln for 1 hour at 400ºC using a chamber flushed with N2 gas. The N2 gas stream reduces O2 concentration in the reactor and removes byproduct gases to a vent. Biochar can be converted to activated carbon by impregnation with K2CO3 and heating to 600°C for 1h8. This chemical activation step was not used prior to acid-treatment of the tomato biochar to determine if the high temperature step described above could be eliminated.

COTS Sorbents

- Two commercial acid-treated sorbents used for ammonia removal were evaluated: Ammonasorb II and Chemsorb 1425.
- Calgon Carbon Ammonasorb II and Molecular Products Chemsorb 1425 are coconut-shell, impregnated granular activated carbons used for the adsorption of airborne ammonia and amines.
- They are impregnated with phosphoric acid that reacts with NH3, converting it to a salt within the carbon thus removing it from the air stream via chemisorption9. Adsorption capacity is exhausted when the available impregnated acid is consumed.
- The adsorptive capacity of these sorbents at 40% relative humidity and 50 ppm NH3 was used as a benchmark for the sorbents derived from C waste biomass.

Sorbents from C Waste

- Carbon waste sorbents were prepared from three sources of biomass (tomato, wheat, and algae; Figure 2). Tomato biochar was produced using slow pyrolysis; Figure 2A). Inedible wheat biomass from a wheat growth experiment was dried at 60°C (Figure 2B). Algal cake obtained from an algal bioreactor was dried at 80°C and broken into pieces (Figure 2C).
- The sorbents were impregnated with H3PO4 using the following modified procedure: Soak 5 g mixed with 100 ml of 50% H3PO4 for 1 hr, then heat the acid mixture for 3 hr at 80°C. The resulting acid-treated sorbent was then vacuum filtered and washed twice with distilled water. Finally, the washed impregnated sorbent was oven dried overnight at 80°C.
- Five sorbents were prepared: Tomato Char (tomato biochar), Tomato Char-Imp (impregnated tomato biochar), Algae (dry algal cake), Algae-Imp (impregnated algal cake), and Wheat-Imp (impregnated wheat biomass). The adsorptive capacities of these acid-treated sorbents were measured using ~50-60 ppm NH3 at 40% relative humidity for comparison with the adsorptive capacities of two commercial acid-treated sorbents. .

Figure 2. Sorbents from Waste Biomass. *A. Tomato biochar B. Wheat dry inedible biomass*, and *C. Algal cake were dried and impregnated with phosphoric acid*

Simulated Spacecraft Gas Streams

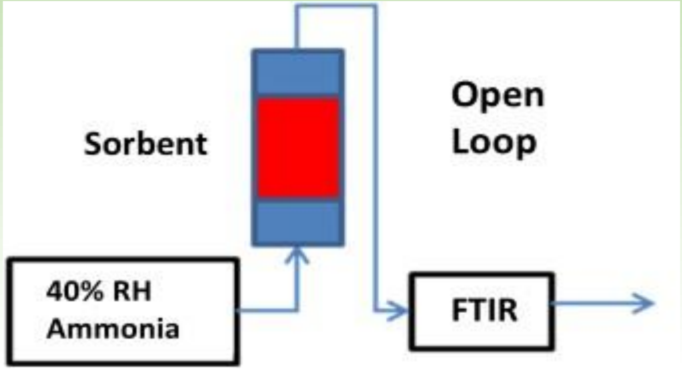


Figure 3. Open loop system. *Measures adsorptive capacities for ammonia of acid-treated activated carbons.*

Open Loop Testbed: An open loop system was used to measure the adsorptive capacity of the candidate acid-treated sorbents (Figure 3).

A gas stream composed of nitrogen was humidified to 30-40% RH and mixed with ammonia. The system delivered between 50-60 ppm of moist ammonia gas to a sorbent tube filled with 40-60 mg of treated carbon at ~ 1 liter/min flow.

The temperature of the laboratory was set at 23 °C. The gas stream passed through the sorbent and the NH3 concentration was measured using a Gasmet 4040 FTIR

Each sorbent was dried as follows: a) Sorbent was loaded into the desorption tube and held in place using two glass wool plugs. b) The loaded tube was weighed and heated to 100 °C with a flow rate of 100 ml/min of N2 in a desorption tube conditioning oven (Scientific Instrument Services, Inc). c) The loaded tube was weighed after 1 h and after 2 h, until its mass was constant. d) The mass difference was ascribed to water and subtracted from the initial sample mass. This process dried the adsorbent and removed moisture adsorbed during storage.

Results – Comparison of Sorbent Capacities

- The adsorptive capacities for moist ammonia of all the sorbents are compared in Figure 4.
- The adsorptive capacities of the COTS sorbents were 48 mg/g and 26 mg/g for Ammonasorb II and Chemsorb 1425, respectively (diamonds, Figure 4). This range of values is a benchmark against which to compare the adsorptive capacities of the C waste biomass sorbents.
- The adsorptive capacities for ~55 ppm NH3 of Tomato Char and Tomato Char-Imp were 8.6 and 33, respectively (circles, Figure 4).
- The capacities for Algae and for Algae-Imp were 25 and 13 mg/g, respectively (triangles, Figure 4). The capacity of Wheat-Imp was 43 mg/g (square, Figure 4).
- This comparison indicates that the Algae, Tomato Char_Imp, and Wheat_Imp sorbents have similar adsorptive capacities for ammonia as the commercial acid-treated sorbents

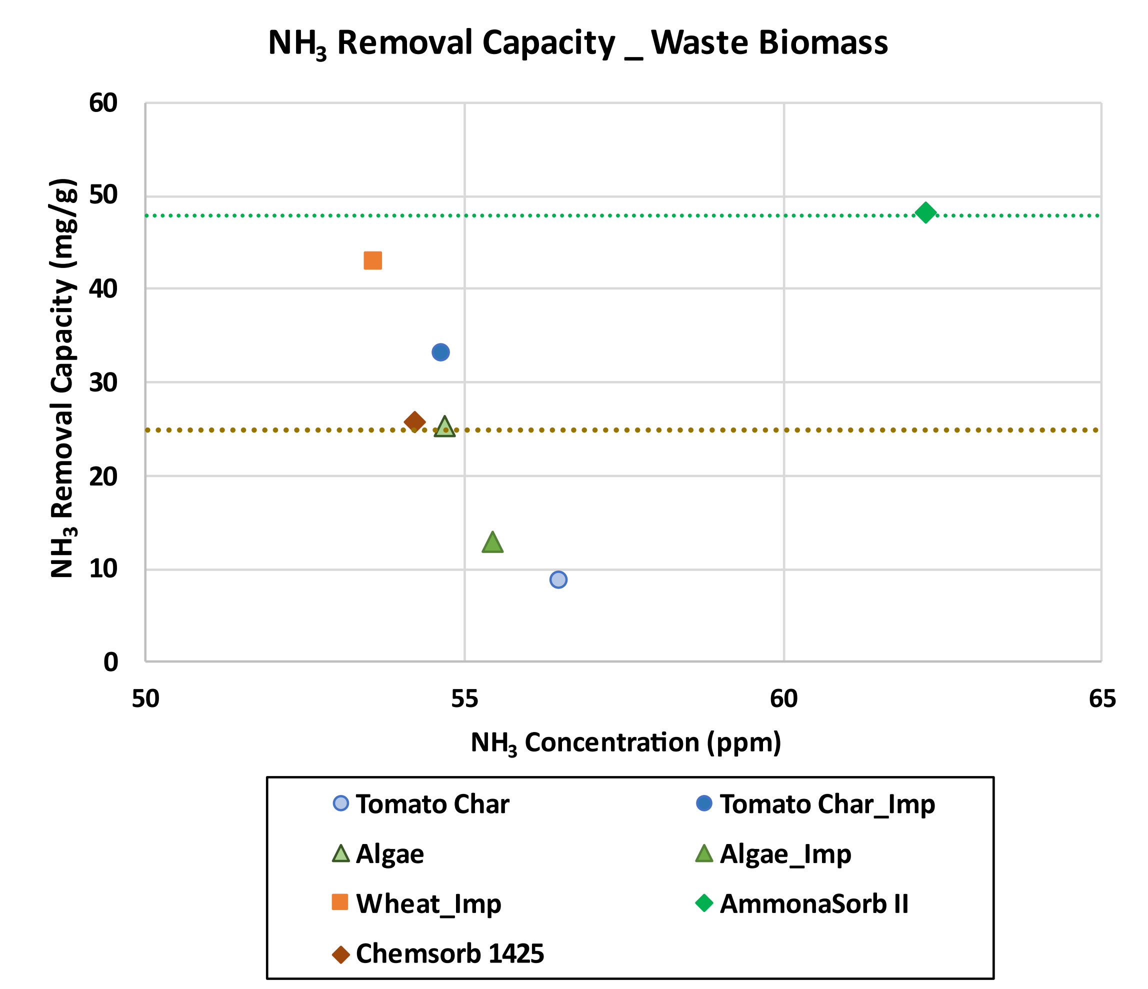


Figure 4. Waste Biomass NH_3 Removal. *Comparison of adsorptive capacities for moist ammonia gas streams of acid-treated sorbents.*

Conclusions

- The methodology for producing impregnated activated carbon from C waste biomass derived from inedible plant biomass and algae was demonstrated. The NH_3 removal capacities of C waste biomass derived sorbents (Algae, Tomato Char_Imp, and Wheat_Imp) were comparable to the NH_3 removal capacities of two commercial acid-treated sorbents (Ammonasorb II and Chemsorb 1425).
- Future work should characterize the dichloromethane and siloxane removal capacities of these sorbents. Sorbents should also be made using inedible biomass from other plant species. In addition, food safety concerns warrant that plant growth in soil amended with used carbon containing NH_3 salts and VOCs be demonstrated to verify that normal plant growth is possible.
- This proof-of-concept effort opens an avenue for repurposing spacecraft C wastes towards the production of candidate sorbents used for ECLS air revitalization architectures.

Questions?

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