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A Report on Air and Water Projects

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GAS-PHASE REVITALIZATION USING BIOFILTERS IN ADVANCED LIFE SUPPORT (**BREATHE II**)

To enable efficient removal of a broad spectrum of gaseous trace contaminants from the cabin air, the design and operation of ALS BREATHe II (Bio-Regenerative Environmental Treatment for Health) system will need to be optimized based on results from bench scale reactors. Thus it is necessary to generate ersatz cabin air and evaluate bench scale reactor performance operated with different reactor configurations, packing material, gas residence time, liquid recirculation rates, contaminant loading rates, etc.

Biofiltration Experiment #1

Ten laboratory-scale biofilters and biotrickling filters were operated for removal of ersatz multi-component gaseous streams representative of spacecraft contaminants released during long-term space travel. The model waste gas stream contained a five-component mixture of acetone, *n*-butanol, methane, ethylene, and ammonia. The waste gas stream was diverted uniformly to six biofilters and four biotrickling filters identical in dimensions for biological treatment, each operated under an empty bed residence time (EBRT) of 30 s. The biofilters were packed with either perlite, polyurethane foam, or a mixture of compost, wood chips, and straw. The biotrickling filters were packed with either perlite or polyurethane foam.

Overall Performance. Both the biofilters and biotrickling filters packed with different media were able to achieve complete removal of acetone, *n*-butanol, and ammonia, all of which being easily soluble compounds, within a short startup period. No methane was removed from any of the bioreactors. The perlite biofilters exhibited the highest performance in ethylene removal followed by the perlite biotrickling filters, the foam biotrickling filters, the foam biofilters, and the compost biofilters.

Biofiltration Experiment #2

As a follow-up to experiment #1, 20 laboratory-scale biofilters and biotrickling filters (duplicate reactors run for each operating strategy) were operated in parallel to study the removal of binary mixture of ammonia and ethylene, in an effort to study the interactions between ammonia and ethylene removal.

Overall Performance. Greater than 95% of ammonia removal has been achieved in all of the 20 bioreactors operated with different operating strategies within 40 days after startup of the bioreactors. Ethylene removal remained low in all the bioreactors during the first 60 days. Starting from day 65, its removal increased rapidly.

BIO REGENERATIVE ENVIRONMENTAL AIR TREATMENT FOR HEALTH (BREATH): INTEGRATED STAR OFF-GAS, CABIN AIR, AND GREY WATER PROCESSING

The BREATH system consists of two packed bed biofilter reactors that simultaneously treat contaminated air and water. The design and optimization of the BREATH reactors involved an in-depth developmental phase where bench scale reactors were used to simulate full-scale systems. During the developmental phase of the project, design parameters such as size, recirculation rates, media type and flow rates were optimized.

BTF (Bio-Trickling Filter) Gas-Phase Loading Experiments. BTF conversion rates were similar to other microbial-based systems treating only liquid-phase contaminants. The introduction of gas phase contaminants did not result in decreased removal of organic constituents. Results indicate the potential for two-phase fluid remediation.

Primary Biodegradation Potential. Similar primary degradation behavior was observed for all surfactants with only a fraction of the parent compound readily biodegradable. Complete removal of these surfactants will be difficult due to formation of by-products that are slowly degraded compared to the parent compound.

Metabolite Biodegradation Potential. Results from this study indicated that biodegradation of the three surfactant metabolites may indeed be unlikely. Metabolite biodegradation kinetics have not been quantified to date, but a future publication will contain the complete biokinetic model with both sets of biokinetic parameters.

BTF Gas-Liquid Absorption Dynamics. Abiotic ammonia mass transfer phenomena within the BTFs was investigated. Ammonia was chosen as a representative gas due to its relatively high solubility and high potential for biodegradation. Results indicated that surfactants did not play a significant role in the abiotic mass transfer of ammonia within the system.

Effects of Hydrodynamics on BTF Fluid Transport. Hydrodynamics in BTFs can strongly be influenced by packing material geometry and hydraulic loading rate. Of the three packings studied, optimal hydrodynamics were observed when Rings were employed.

MEMBRANE PROCESSES IN ALS

This project has been divided into two thrusts. The first involves modification and synthesis of novel new membranes to decrease fouling and increase salt rejection for water reuse applications. MF (microfiltration) membranes will be modified to reduce biofouling and novel new NF (nanofiltration) membranes will be synthesized to reduce fouling and increase salt rejection. NF membranes operate under much lower operating pressure than RO membranes, resulting in significantly reduced ESM for the system.

The second thrust focuses on reducing surfactant fouling of NF membranes. It is known the water recover unit processes preceding the membrane systems will not remove all surfactant from the water. Thus, it will be necessary for the RO system to reject all remaining surfactant monomers and micelles. Fouling is an issue of concern.

Thrust 1: Modification and synthesis of membranes to reduce fouling and increase rejection.

Membrane modification. MF membranes will be used as pretreatment for the NF membranes. The large pore size in MF membranes results in lower pressure and higher flux than for the other pressure driven membranes, making MF membranes ideal for the low ESM requirements in ALS NSCORT. The largest problem with the MF membranes will likely to due to biofouling, as these membrane follow directly behind BREATHe, which may leak biosolids. The MF membranes will reject biosolids, but these materials may accumulate on the membrane surface and reduce flux.

Commercially available polyether sulfone (PES) membranes were modified using UV initiated grafting with acrylic acid. PES membranes were chosen for their photosensitivity, wide pH tolerance, and good resistance to oxidants including chlorine. The modified MF membrane exhibited enhanced flux after modification, while the modified UF membrane showed reduced flux following modification.

Synthesis and Characterization. Cellulose acetate (CA) membranes were spun onto a polypropylene backing in order to synthesize new NF membranes for increased rejection and decreased fouling in the post treatment phase.

Thrust 2: Quantification of surfactant fouling using RO membranes

The ALS research community has identified two surfactants, sodium laureth sulfate (SLES) and disodium cocoamphoacetate (DSCADA) as likely candidate soap for hygiene purposes during long duration human space missions. RO and NR membranes systems are widely accepted as effective techniques in the removal of pollutants that are otherwise difficult to eliminate using biological and physical treatment methods. Two commercially available membranes, ESPA 1 (RO) and ESNA 1 (NF) (Hydranautics, Riverside, CA) have been chosen.

Rejection of SLES from the RO membrane was measured using a COD analyzer. Initial results with a 100 mg/L surfactant feed indicate an average of 99% removal of the surfactant using this membrane.

MINIMIZING EQUIVALENT SYSTEM MASS FOR A REGENERATIVE LIFE-SUPPORT SYSTEM BY OPTIMIZING KINETICS AND ENERGETICS OF MAJOR BIO-TRANSFORMATIONS – Development of a System for Disinfection of Potable Water Based on the Combined Application of UV Radiation and Iodine

The nature of long-term space missions that involve extended stays by astronauts in locations beyond near-Earth orbit is such that complete water reuse is required. To address this need, a potable water disinfection system was developed that involves the combined application of germicidal ultraviolet (UV) radiation and iodine. The combined application of UV and iodine allows for the inclusion of disinfectants that accomplish microbial inactivation.

Development of Iodine-Based Disinfection System

The development of the iodine-based disinfection system involved four specific tasks, as outlined below. The first task involved development of a tool that allowed iodine species and concentrations to be predicted based on system characteristics, such as pH and oxidation-reduction (redox) potential. The second task involved an investigation of the disinfection efficacy of UV radiation and iodine using a challenge microorganism (*Bacillus subtilis* spores). The third task involved an investigation of the behavior of iodide-iodate as chemical actinometer for on-line, real-time measurement of germicidal UV intensity through a new method called local actinometry. The actinometer was shown to be effective for this purpose. Lastly, the fourth task involved the development of a means to utilize the photoproduct of the actinometer as a residual disinfectant. Emphasis was placed on accomplishing recovery of the iodine, providing a beneficial chemical residual, and minimizing chemical requirements.

Development of UV (Ultra-Violet) -Based Disinfection System

In conjunction with NASA's interests in conducting long-duration human space travel, a UV system was designed based on XeBr (Xenon-Bromide) excimer lamp technology. NASA had indicated that UV systems used in long-term space missions should be free of mercury; this constraint represents an important departure from virtually all terrestrial applications of UV radiation, which are dominated by mercury-based UV lamps.

The behavior and capabilities of the reactor system were measured using conventional biosimetry (based on *B. subtilis* spores as the challenge organism) and using a technique that was recently developed by the Blatchley group known as Lagrangian actinometry. In this latter method, microspheres containing a photosensitive dye are imposed on a UV reactor system. The results of these tests indicated that the prototype reactor is highly efficient and capable of accomplishing inactivation of relevant microbial pathogens in potable water supplies.