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SPACE LIFE SUPPORT TECHNOLOGY APPLICATIONS TO TERRESTRIAL ENVIRONMENTAL PROBLEMS

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ABSTRACT

Many of the problems now facing the human race on Earth are, in fact, life support issues. Decline of air Quality as a result of industrial and automotive emissions, pollution of ground water by organic pesticides or solvents, and the disposal of solid wastes are all examples of environmental problems that we must solve to sustain human life. The technologies currently under development to solve the problems of supporting human life for advanced space missions are extraordinarily synergistic with these environmental problems. The development of these technologies (including both physicochemical and bioregenerative types) is increasingly focused on closing the life support loop by removing and recycling contaminants and wastes to produce the materials necessary to sustain human life. By so doing, this technology development effort also focuses automatically on reducing resupply logistics requirements and increasing crew safety through increased self-sufficiency. This paper describes several technologies that have been developed to support human life in space and illustrates the applicability of the technologies to environmental problems including environmental remediation and pollution prevention.

INTRODUCTION

On previous missions, spacecraft life support systems have used open-loop, non-recycling chemical and mechanical technologies. These technologies were simple and sufficiently reliable to support humans for missions of relatively short duration. For NASA's planned Space Exploration Initiative (SEI), however, life support technologies must address a new and different set of requirements. These include longer mission durations and the need for closure of the life support loop (through material recycling) to minimize resupply logistics and maximize crew safety. Meeting these requirements involves new methods of life support which emphasize regenerative technologies.

The development of these regenerative life support technologies holds a promise which extends far beyond the SEI program, however. Many of the problems the human race must grapple with on Earth are fundamentally life support issues. Atmospheric changes caused by air pollution, and which contribute to the greenhouse effect or to depletion of the ozone layer present critical challenges to the agricultural and ecological sciences. Pollution of water by fertilizers, organic pesticides or chemical solvent presents serious health problems to our population. The recycling of solid wastes is another example of a problem for which we must find an appropriate technological solution. The objective of this paper is to describe some technologies currently under development for life support applications, and to outline how they might be applied to help solve some of these pressing environmental problems.

LIFE SUPPORT FUNCTIONS

Human beings require substantial amounts of material to sustain life. Including the water required for showers, personal hygiene, and food preparation, without recycling it takes over 3 and one-half tons of food, water and oxygen to support an average person for one year. If clothes wash water is added, the total weight of required life support materials more than doubles. Clearly, recycling life support materials is essential to minimize resupply for space missions.

The basic functions necessary to support human life include water recycling, solid waste processing, atmosphere regeneration, and food production. This paper presents examples of environmental applications of technologies which fulfill the first two of these functions. The technologies available to provide basic life-support functions fall into three categories: physicochemical , bioregenerative, and hybrid. Physicochemical technologies are those which use chemical reactors and/or mechanical devices (such as fans, pumps, and filters). Bioregenerative technologies incorporate living organisms such as plants, algae, or bacteria to supply specific life support functions. Hybrid systems are created by combining components of both the technologies that are best suited to perform specific life support functions. Because of the clear need to reuse materials within the life support system, we are also focused on regenerative technologies which support recycling.

WATER RECYCLING

The recycling of water is one of the most significant challenges facing life support designers, because of the prodigious amounts of water used by people. Two types of water require processing for recycling, gray and black. Gray water is the effluent resulting from basic hygiene activities, food preparation, and collection of condensate from the atmosphere. Black water carries urine and fecal waste materials.

The physicochemical technologies developed for recycling water include simple distillation, filtration (e.g., reverse osmosis, hyperfiltration) and phase change processes (e.g., Vapor Compression Distillation (VCD), air evaporation). The bioregenerative processes used most frequently in water recycling are bacterial filters. Water reclamation by communities of higher aquatic plants and their associated bacteria is a relatively new method of bioregenerative processing (Wolverton, et. al., 1983). Waste water is pumped through a bed of aquatic plants which, along with the bacteria around their roots, remove contaminants. This type of system is being evaluated for tertiary processing of sewage water in several cities (e.g., San Diego).

Commercial waste water treatment plants generally use a hybrid approach incorporating both physical and bacterial filtration to treat water before discharging it into the environment. Such treatment does not normally remove all of the contaminants, and as a consequence the treated water is not purified sufficiently well to recycle directly for drinking, washing, or cooking.

Lockheed, in conjunction with Louisiana State University, is currently conducting research and advanced development work in which selected bacterial species are used to purify water for direct recycling (Miller, et. al., 1992). By matching the contaminant removal capabilities of bacterial species to the contaminants in the water, high levels of water purification can be achieved. Several such bacterial systems are now in operation, and some are being applied in site restoration efforts to purify polluted ground water supplies. In such applications, ground water is pumped through the bacterial reactor. After the bacteria metabolize the contaminants, the cleaned water may be returned to the aquifer.

Figure 1 provides a block diagram of an immobilized bioreactor for studying bacterial degradation of organic contaminants in the laboratory. Figure 2 illustrates both the laboratory and field (site remediation) bioreactors. The laboratory reactor is configured to support degradation studies in either plug flow or recycle configurations. Figures 3 and 4 show typical performance data for this type of laboratory reactor. In Figure 3, the degradation of two different concentrations of phenol in water was evaluated. As this figure shows, removal at the high phenol concentration was extremely high, averaging over 99.5% during the test period. Removal at the low phenol concentration averaged about 97% over the 8-day test.

Figure 4 shows degradation of three chlorinated hydrocarbon species during long duration tests of the bioreactor. Minimum efficiency was about 60% for TCE a 12ppm in water, but average efficiencies over the 25 day period were in the 80-95% range. Operation over long period of time may require addition of nutrient supplements to ensure the bacteria maintain a high operating efficiency.

WASTE PROCESSING

Due to the short durations of previous missions, waste processing has had little need to advance beyond the technologies for collection and storage. On the Mercury through Apollo missions, human wastes were stored in holding compartments. Germicides were added to inhibit bacterial degradation of the wastes. Both Skylab and Shuttle dry and store organic waste materials. Other solid wastes (food and drink packages, tissues and wipes, etc.) are normally bagged and returned to Earth.

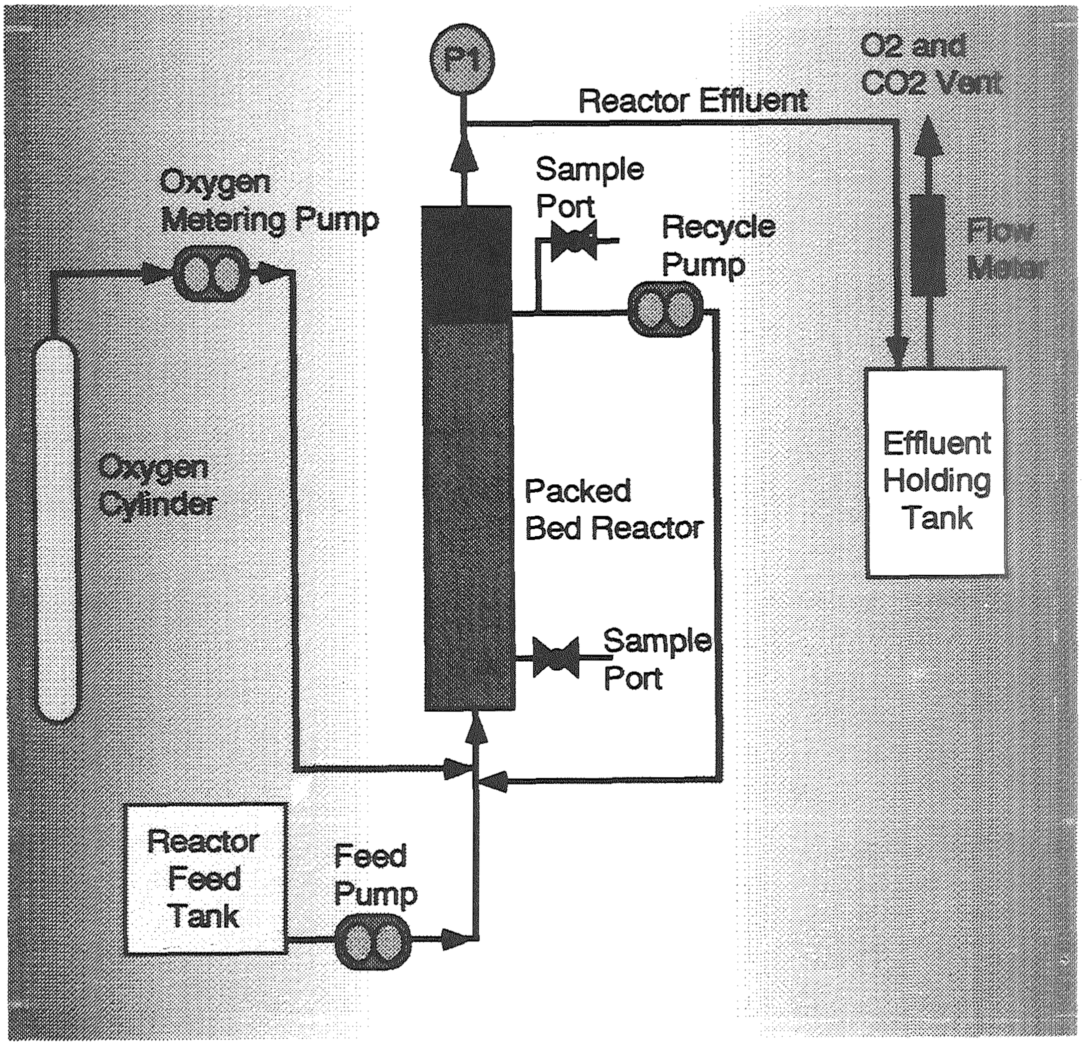


Figure 1. Block diagram of immobilized bioreactor

Physicochemical technologies for waste processing include incineration, electrochemical oxidation, wet oxidation, and supercritical wet oxidation. These systems typically require large amounts of electrical energy, but many highly toxic compounds can be effectively broken down by the intense physical conditions they produce.

Bioregenerative technologies include bacterial reactors (both aerobic and anaerobic) and combination higher plant/bacterial systems. Aerobic bacterial systems typically require higher energy inputs to maintain oxygenation (e.g., aerating pumps, mixers). Anaerobic systems require very little energy, but have very slow process rated, and the anaerobic bacteria are more susceptible to changes in environmental conditions (Wolverton, et. al., 1983).

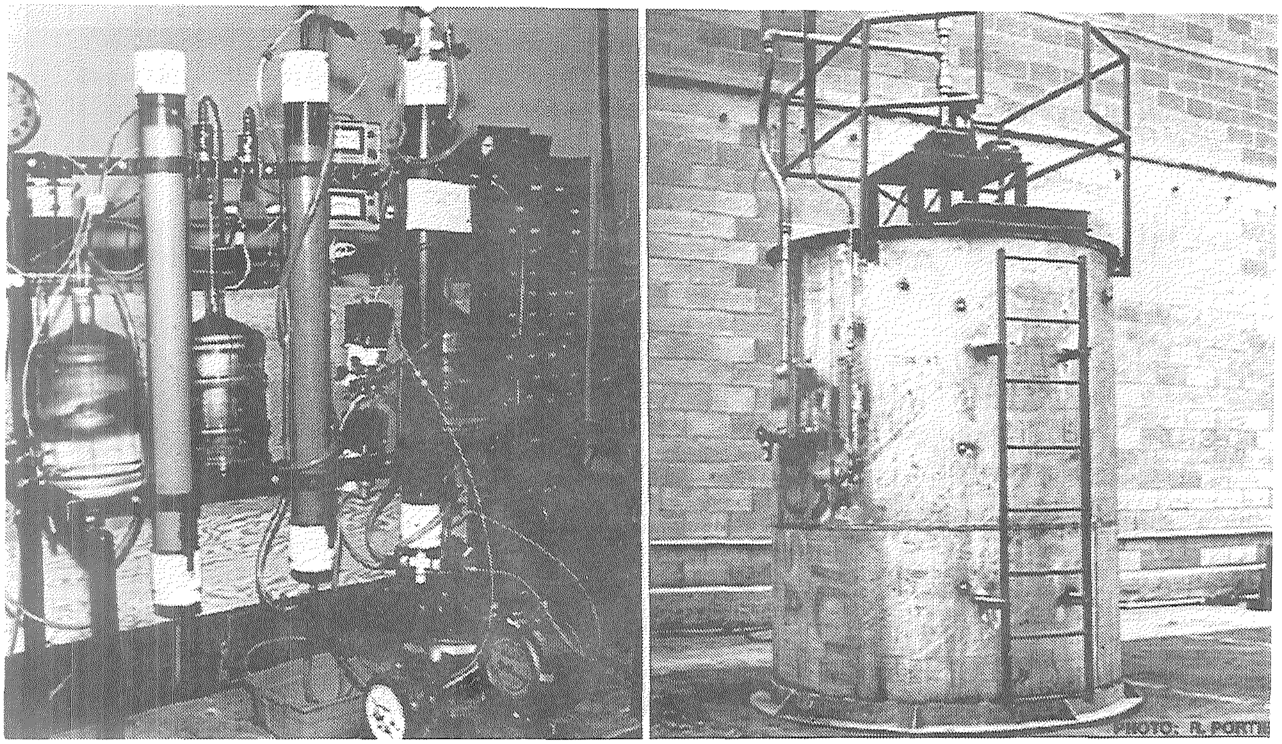


Figure 2. Laboratory bioreactor (left) and field bioreactor for site remediation

One of the methods Lockheed has investigated for processing solid wastes and highly toxic materials is wet oxidation. Wet oxidation is a flameless combustion process carried out at moderate temperatures (300=650°F) and moderate to high pressures (450-2500 PSIG). Pure oxygen gas or compressed air can be used to supply oxygen for the reaction process.

The products of the oxidation process vary, depending on the nature of the waste stream, and the operating conditions of the reactor. Under ideal operating conditions, the products include only CO_2, N_2, H_2O and dissolved inorganic salts. Figure 5 shows a laboratory wet oxidation reactor test bed, along with a mobile reactor test bed and the mobile test bed control room. These reactors were developed and extensively tested in the late 1970's.

Figure 6 illustrates test results obtained by applying the mobile test bed reactor to a variety of plant effluents. As indicated, reduction of total organic carbon in these (TOC) effluents was always at leat 44-45%, while the removal of the specific constituent of interest never fell below 88%. These operating efficiencies are controllable by altering the conditions under which the oxidation occurs.

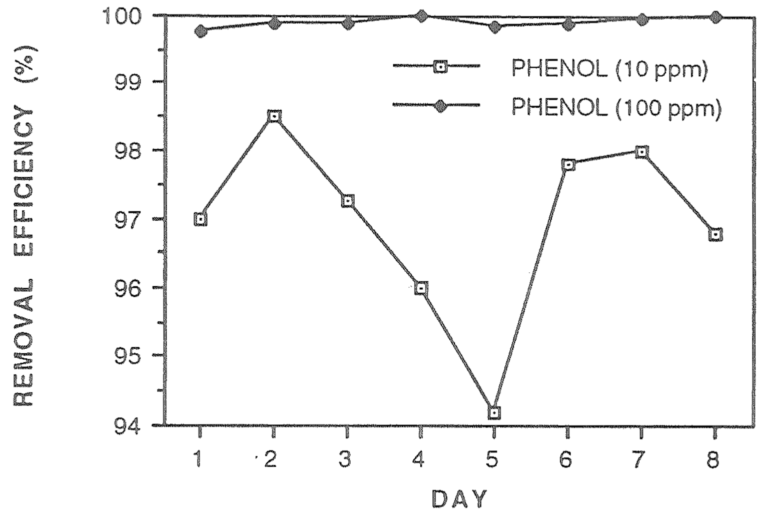


Figure 3. Removal of phenol from water by a microbial bioreactor.

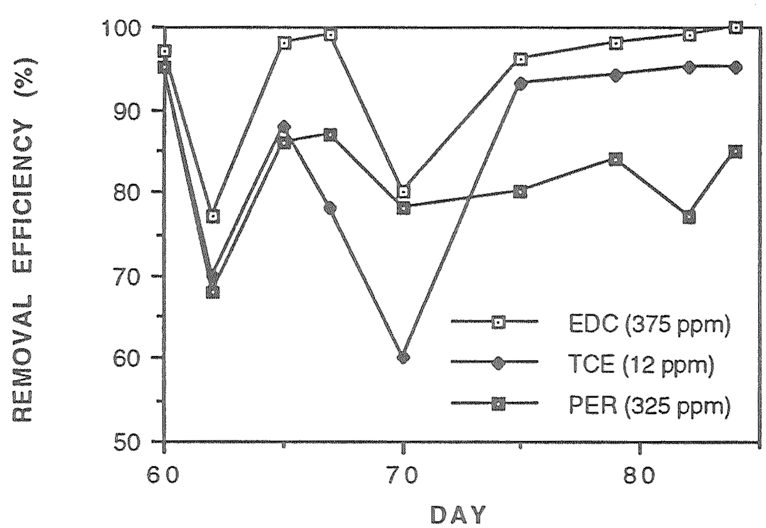
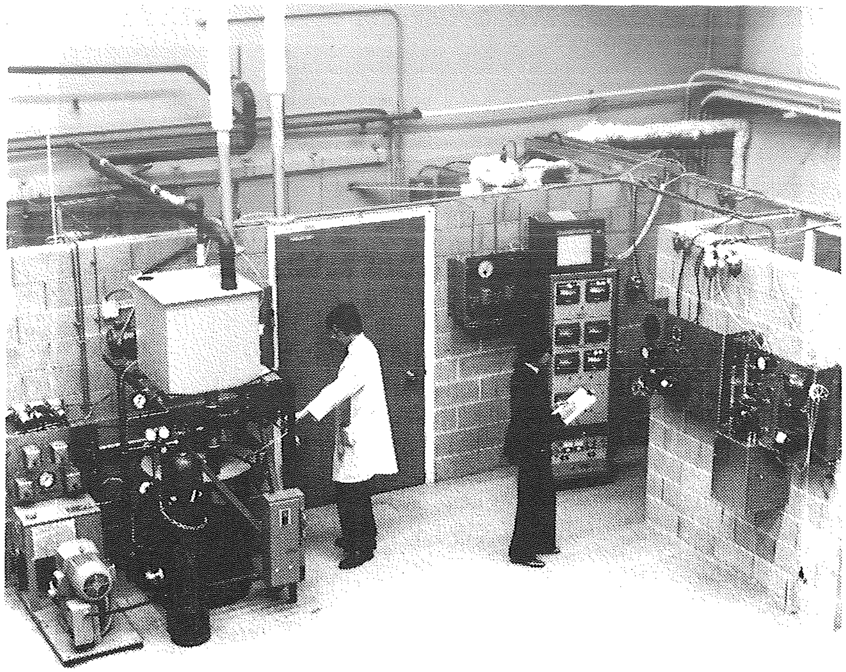


Figure 4. Removal of chlorinated hydrocarbons from water by a microbial bioreactor.



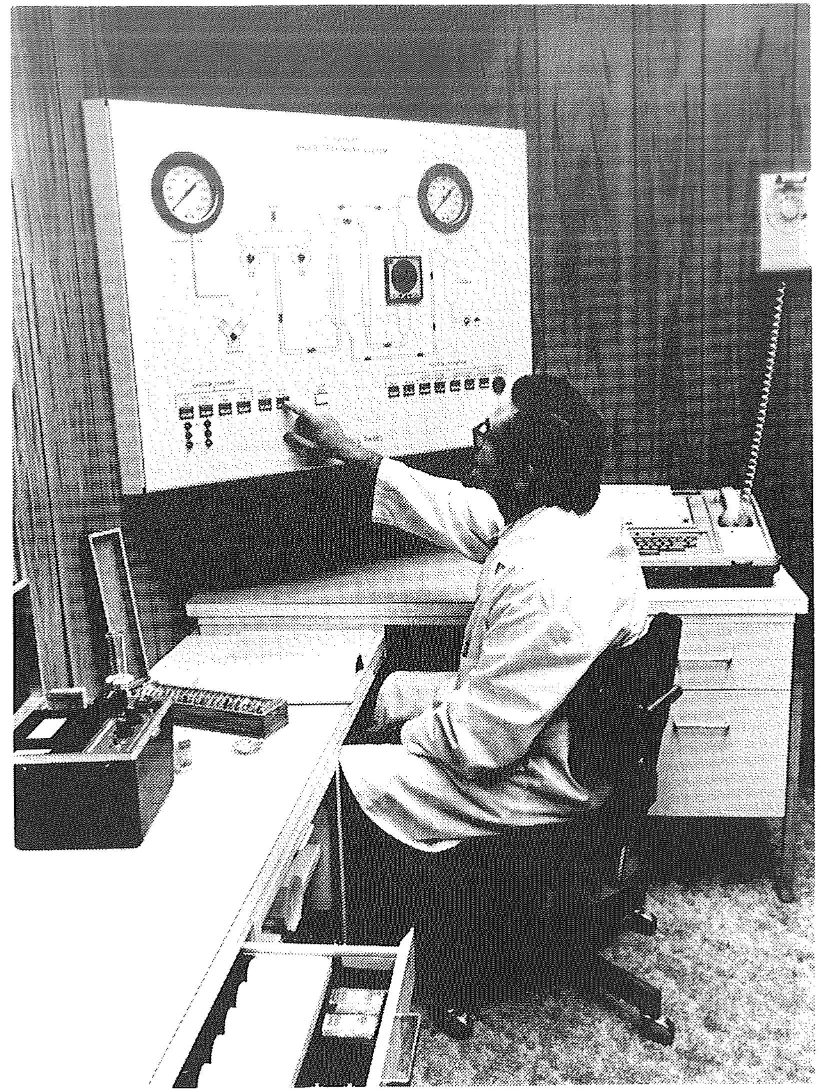


Figure 5. Lockheed wet oxidation reactors: laboratory research test bed, mobile test bed, and mobile test bed control room.

Waste Source (Specific Constituent)	Operating Conditions		TOC Reduction (%)	Specific Constituent Removed (%)
	Temperature (°F)	Pressure (PSIG)		
Benzoic Herbicide Process (Dichlor-nitrobenzoic acid)	500	1,200	45	88
Acrolein Process (Acrolein/allyl alcohol)	550	1,500	44	99
Triazine Herbicide Process (Atrazine derivatives)	500	1,200	46	100
Xylene Process (Aromatics)	600	2,000	68	92
Antiozonant Process (Aromatics)	450	900	64	100
Hydrazine Process (Hydrazine)	400	700	49	100
Urea-Formaldehyde Process (TKN)	250	300	60	92
Coke Plant Ammonia Still	550	1,500	90	100
Synthetic Rubber Process (Surfactants)	600	2,000	67	95

Figure 6. Results obtained from the mobile test bed reactor when applied to a variety of plant effluents.

CONCLUSION

Many of the environmental problems we must solve over the next two decades are life support problems. As a consequence, spacecraft life support technologies, or modifications of those technologies, can provide us with additional methods of solving the problems. In the appropriate configurations, these technologies can contribute substantially to pollution prevention, site restoration, and recycling. Ultimately, these technologies, which are now being developed to support the life of humans on other planets, may play a crucial role in sustaining human life on the planet we call home.

LITERATURE CITED

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