Anaerobic Digestion of Wastewater for Producing Life Support Resources Within a Mars-Based Space Camp

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ABSTRACT

NASA's proposal to send humans to Mars by the end of Year 2030 has prioritized R&D needs to support human life on the planet. Waste management within the space camps housing humans on Mars and the Moon is a key research area for NASA. This research needs to produce technology that has an excellent treatment efficiency, reasonable payload, low energy use, and ideally, can recycle generated waste into useful products to sustain life in the camp. The Louisiana NASA EPSCoR R&D program via the Louisiana Board of Regents and LaSPACE is working in concert with the University of Louisiana to develop the BIOSYS system which is a waste management system for use on Mars and the Moon that is designed to be both energy- and oxygen-use neutral and is capable of meeting treatment goals while producing additional life support resources. The primary goal toward developing the BIOSYS system is to treat all human-derived H_2O-based wastes and produce useful source of energy and recover the nutrients. A key component of this work is the development of a highly efficient anaerobic digestion step to convert the bulk of the wastes into hydrogen or methane while removing over 60% of the pollutants from the water stream. Anaerobic digestion is favorable over aerobic digestion since it can operate in the absence of oxygen which is not readily available in these planetary camps. Food waste from the university cafeteria along with a synthetic wastewater that mimics the wastewater generated in space has been tested in bench-scale digester microcosms to determine initial conversion efficiencies using standard digestion operational parameters. Methane has been produced and effective removal of the COD has been observed. Significant amounts of hydrogen were also produced but activity decreased over time within the batch systems tested. Various parametric test results indicate promise yet significant optimization is needed to reach target goals. Further R&D is planned that should address these process limitations.

OBJECTIVE

The main objectives of anaerobic digestion are to 1) reduce maximum pollutant, that is measured as chemical oxidation demand (COD) of a low loaded wastewater and 2) produce biogas, mostly hydrogen and methane which can be used to power Mars camps and transport vehicles [1,2,3,4,5].

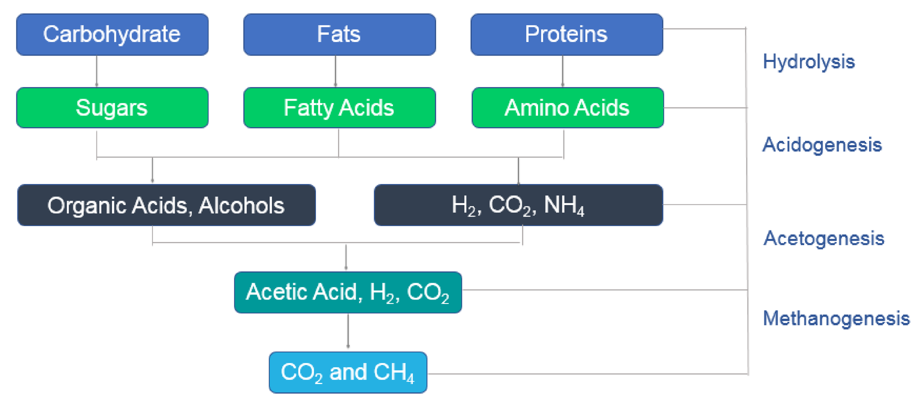

Fig. 1 Anaerobic digestion mechanism flow diagram

Hydrolysis of carbohydrate
1. Carbohydrate + $2H_2O \rightarrow C_6H_{12}O_6 + 2H_2$

Acidogenesis:
2. $C_6H_{12}O_6 + 2H_2 \longleftrightarrow 2(CH_3CH_2COOH) + 2H_2O$
3. $C_6H_{12}O_6 \rightarrow 3\ (CH_3COOH)$

Acetogenesis:
4. $C_6H_{12}O_6 + 2\ H_2O \longleftrightarrow 2CH_3COOH + 2CO_2 + 4H_2$

Methanogenesis:
5. $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$
6. $CH_3COOH \rightarrow CH_4 + CO_2$

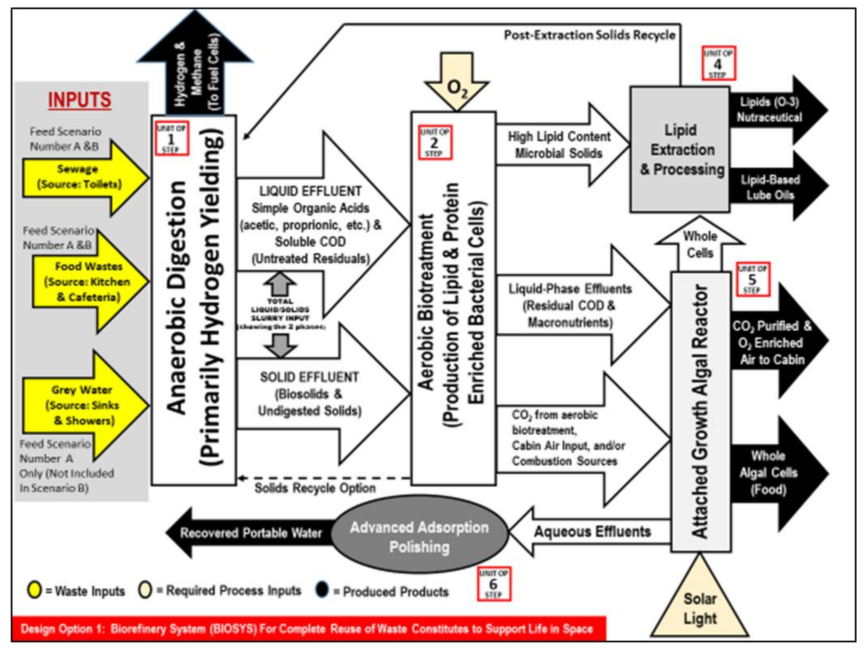

Fig. 2 BIOSYS Process flow diagram

The sources of wastewater to the anaerobic digester are the H_2O based waste which consists of sewage wastewater (black water), water from the shower and sinks (grey water), and kitchen wastewater.
The effluents from the anaerobic digester is sent to aerobic process for further pollutant removal while the off gases produced, which is mainly hydrogen and/or methane is used to power the base camps.

METHODOLOGY

Fig 3. Microcosm set up for batch digestion

Fig 4. DRB 200 Reactor block and Spectrophotometer for COD analysis of samples

Fig 5. Gas Chromatograph for biogas composition in headspace

Experimental design:
- Synthetic waste water (SWW) was prepared to simulate the waste water generated in space.
- 3 different experimental sets were prepared with 3 replicates totaling to 9 observations
- Anaerobic sludge from anaerobic digester of wastewater treatment plant was taken to seed the synthetic waste water with methanogens.

Reactor Conditions:
- 500 ml microreactors with 3 airtight ports were used [Fig. 3]
- Working volume of 250 ml
- Reactors were digested at 37 ºC which is the mesophilic range

Parameters of interest:
- pH and Oxidation Reduction Potential
- Chemical Oxidation Demand
  - Initial chemical oxidation demand of samples were set between 600-1500mg/L
  - The COD were measured using HACH High Range test kits [Fig. 4]
- Biogas Composition
  - CO_2, H_2, CH_4 composition was measured using Gas Chromatography [Fig. 5]
- Total Solids %
  - TS% was calculated following APHA standards

Table 1. Composition of synthetic wastewater

Component	Amount (mg)
Cafeteria food waste (salad)	150
Peanut Oil	100
Urea	50
Starch	150
Glucose	100
Yeast Extract	37.5
Peptone	25
NPK fertilizer+	50
Sodium acetate	75
Ammonium chloride	10
Sodium chloride	15
Potassium Chloride	20
Calcium chloride	15
Ferrous sulphate	1
Magnesium phosphate	6
Potassium phosphate	0.5
Casein	2.5
Bile	5
Dried dog food	75
Dog feces	100

Table 2. Experimental design

Sample ID	Vol seed (mL)	Vol SWW (mL)	Vol DI water (mL)
Control	12.5	0	237.5
SS	12.5	237.5	0
SD	0	250	0

Table 3. Initial and final values of parameters of interest

Parameter	Control	SS	SD
Initial Ph	7.70 ± 0.05	7.75 ± 0.02	7.43 ± 0.02
Initial COD (mg/L)	830	1444	638
Final pH	6.46 ± 0.03	6.68 ± 0.01	6.78
Final COD (mg/L)	502	533	78
% COD reduction	39.5	63	88

The pH of all the samples were set to be neutral to slightly basic . Literature has shown methanogenic inhibition at lower inhibition at lower pH[1]
The initial COD of the samples ranged from 600 mg/L – 1500 mg/L due to the addition/ absence of the seed from anaerobic digester and is the typical COD level of wastewater generated in space

RESULTS

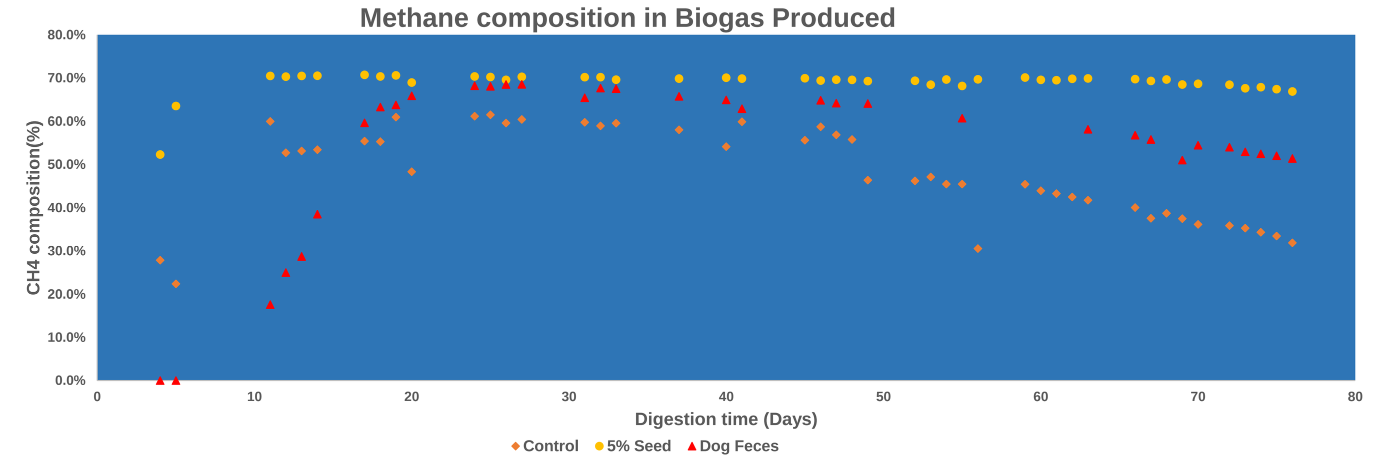

Table 3. Total solids % of the effluent

ID	Total Solid %
Control	11.95
SS	6.62
SD	2.68

Fig 6. Total Suspended solid on dried filter paper for Control, SS, and SD (left to right).

- The samples experienced a lag time for methane production, longer for the unseeded SWW
- The seeded SWW produced biogas with the maximum amount of methane (71%) and remained stable for a longer time as compared to the unseeded SWW.
- Small amount of methane is produced in the unseeded SWW however, the methane production declined as the digestion continued.
- The unseeded SWW had the lowest total solids% than the control and the seeded SWW due to the absence of the seed which has biomass.

FUTURE WORK:

8L reactors are built for anaerobic co-digestion of wastewater with food waste and dog feces. A second attached growth reactor for the effluents from the first digester will be built for additional biogas production and reduction of the pollutants.

Fig 7,8 . Reactor set up for anaerobic digestion

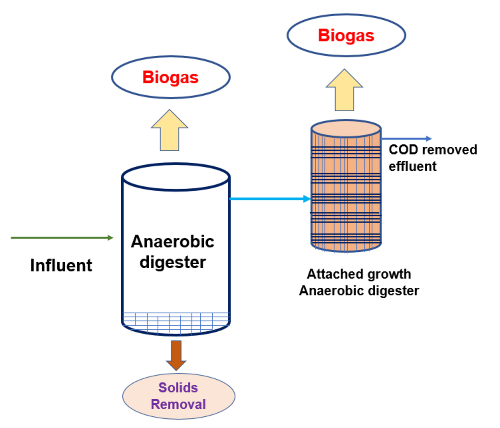

Fig 9. Overall reactor setup including attached growth anaerobic digester.

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