Production of methane and water from crew plastic waste

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Abstract

Recycling is a technology that will be key to creating a self sustaining lunar outpost. The plastics used for food packaging provide a source of material that could be recycled to produce water and methane. The recycling of these plastics will require some additional resources that will affect the initial estimate of starting materials that will have to be transported from earth, mainly oxygen, energy and mass. These requirements will vary depending on the recycling conditions. The degredation products of these plastics will vary under different atmospheric conditions. An estimate of the the production rate of methane and water using typical ISRU processes along with the plastic recycling will be presented.

Outline

- Amount of plastic waste produced
- Pyrolysis techniques and products
- Product use (what do we want to make?)
- Reactor designs/ previous work
- Projected products
- Use of leftover propellants
- Possible use of biodegradeable plastics
- Potential use of biological breakdown
- Possible products/ timeline / power savings?
- ESM to be determined
- Chemistry vs biology – architecture may decide which one is more suited toward the mission design

Need for recycling of resources

- In order to minimize resupply needs from Earth, we must maximize use of all resources
- One aspect of that is production of water and methane from ‘waste’
- ‘waste’ includes plastic food packaging, human dry solid waste, and dry food waste
- Experimental work will focus on plastic food packaging

Resources available from waste

- Values based on data from ISS and Space Shuttle, given in quantity per crew member day (CM-d)

Type	kg/CM-d	% of total waste
Plastic food packaging	0.262	74.5
Crew dry solid waste	0.028	8
Food attached to plastic packaging	0.062	17.5

Ref 2-3

Thermal analysis of plastic packaging currently used on ISS and Shuttle

- 4 plastic pouches obtained
- Polymer composition identified for samples

Table I. Composition of the plastic bags used on the ISS and Shuttle and quantity used

Pouch Description	Composition
Clear Pouch – XX115	PE/PA/EVOH/PA 4.5 mil total thickness
Green Pouch – Altivity MRE-70467	40 Gage PET/adhesive[a]/60 gage Biax/ Nylon/ adhesive[a]/0.0004 Aluminum foil/adhesive/3.2 mil cast polypropylene
White Pouch	0.00048” Polyester / 0.0007” White LDPE / 0.0005” Aluminum foil / 0.002” Surlyn
Beverage Pouch	0.00048” Polyester / 0.00050” Aluminum foil / 0.0040” LLDPE & LDPE
Plastic Part	LDPE, Silicone valve, patch PET/Al, Foil/LLDPE+LDPE

[a] The adhesive used to bind the layers is polyethylene

Approximate elemental composition of polymers for plastic packaging

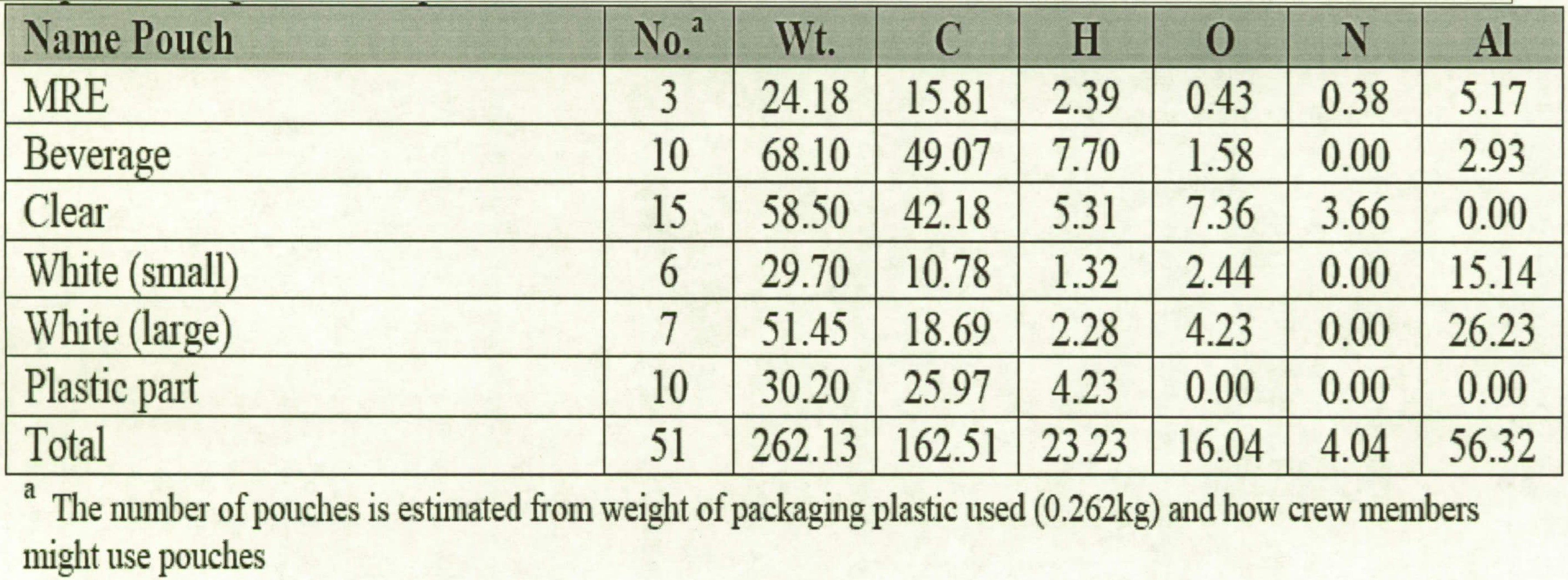
Weight percent of the elements in each of the polymers

Polymer Acronym	Wt% C	Wt% H	Wt% O	Wt% N
PE	86	14		
HDPE	86	14		
LDPE	86	14		
LLDPE	86	14		
PET	63	4	33	
EVOH	67	11	22	
PA	69	6	13	12
CPP	86	14		
Surlyn	82	13	6	
Polyester	63	4	33	
Biax Nylon	69	6	13	12

- Basis for estimating amount of oxygen available in polymers to oxidize nitrogen, sulfur, carbon and hydrogen

Elemental generation from plastic packaging estimated per crew member day

Crew member daily estimated packaging used and generation rates of elements in grams (g/CM-d)



Name Pouch	No.[a]	Wt.	C	H	O	N	Al
MRE	3	24.18	15.81	2.39	0.43	0.38	5.17
Beverage	10	68.10	49.07	7.70	1.58	0.00	2.93
Clear	15	58.50	42.18	5.31	7.36	3.66	0.00
White (small)	6	29.70	10.78	1.32	2.44	0.00	15.14
White (large)	7	51.45	18.69	2.28	4.23	0.00	26.23
Plastic part	10	30.20	25.97	4.23	0.00	0.00	0.00
Total	51	262.13	162.51	23.23	16.04	4.04	56.32

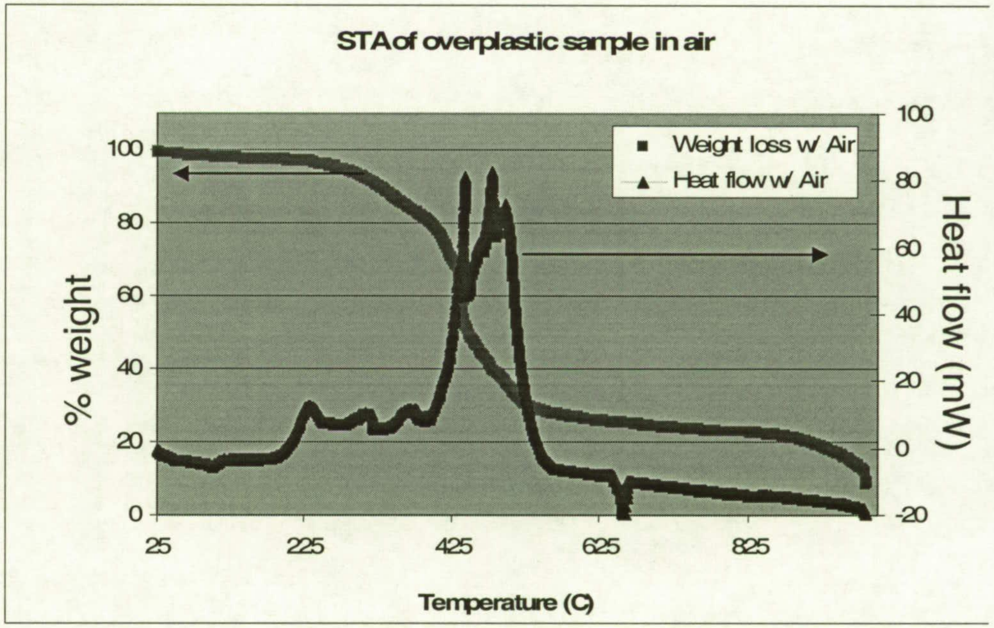
[a] The number of pouches is estimated from weight of packaging plastic used (0.262kg) and how crew members might use pouches

DSC/TGA

- Thermal analysis analytical tool to study the behavior of a sample as function of temperature
- DSC (differential scanning calorimetry) provides information on heat flow during the analysis (endothermic/exothermic)
- TGA (thermal gravimetric analysis) provides information on the weight change as a function of temperature
- STA (simultaneous thermal analysis) combines DSC/TGA into a single analytical tool

Example of STA curves

- Endothermic curve (ex. Pyrolysis, Aluminum melting)
- Exothermic curve (incineration or combustion process)
- Comparing the weight loss with the heat flow indicates how much of the sample lost weight due to each process
- Purge gas can be changed to simulate different atmospheres (presence of oxygen or lack of oxygen)



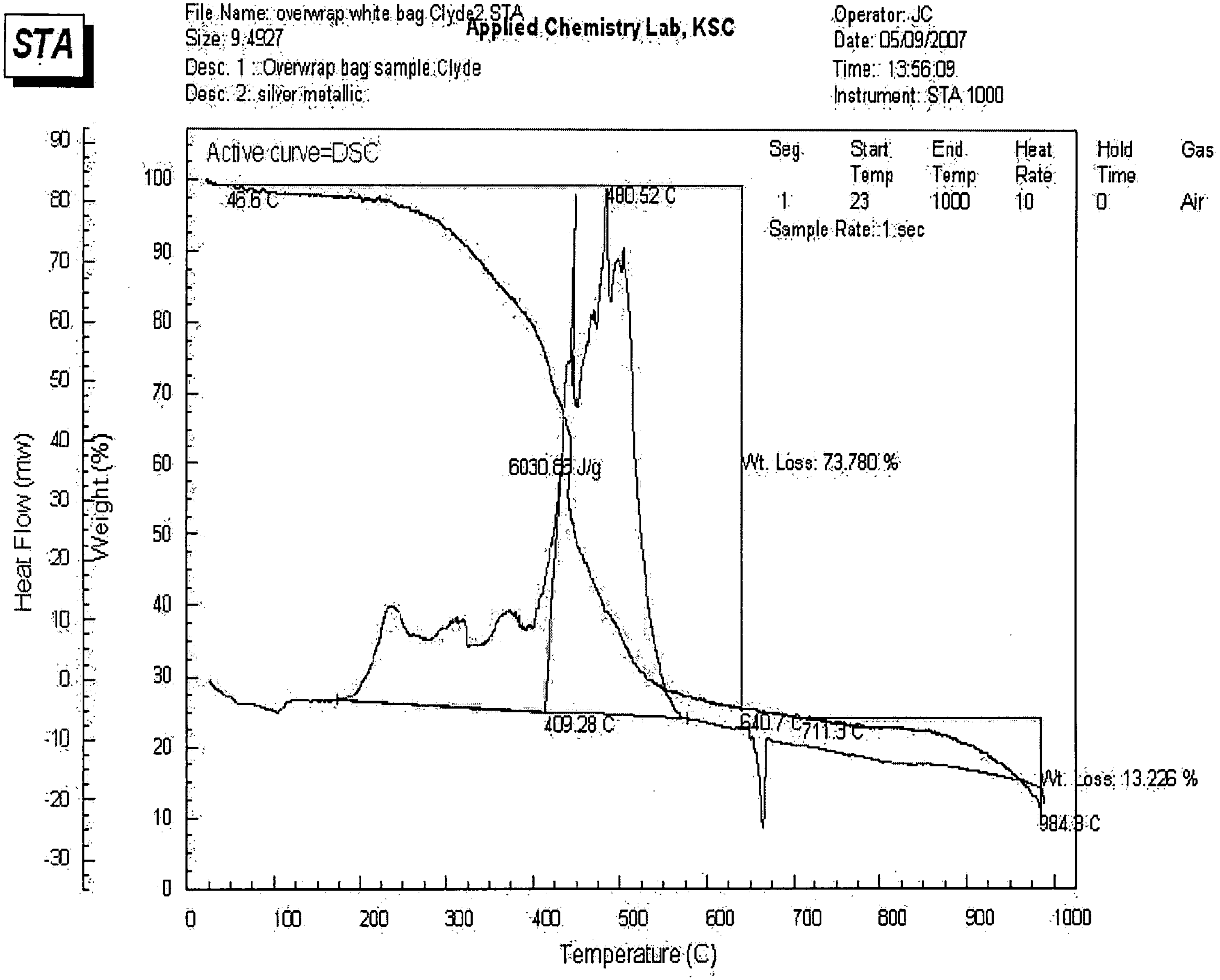
Experimental Conditions

- 8 -15 mg samples were analyzed in platinum pans
- Samples taken from 25 – 1000 °C at a rate of 10 °C/min
- Atmosphere during analysis was either air or argon, the presence of oxygen provided excess oxygen for combustion of samples for comparison to an inert atmosphere

MRE pouch analysis

- Polymer composition of sample
  - Polyethelene 160-300 °C
  - Polyethelene terephthalate 380-515 °C
  - Poly(vinyl alcohol) 400-500 °C
  - Polyamide (Nylon)
- Sample also contains aluminum foil layer
  - Endothermic dip at 660 °C corresponds to melting pont of aluminum

STA of Overwrap Sample in Air



File Name: overwrap white bag Clyde2.STA
Size: 9.4927
Desc. 1 : Overwrap bag sample Clyde
Desc. 2: silver metallic

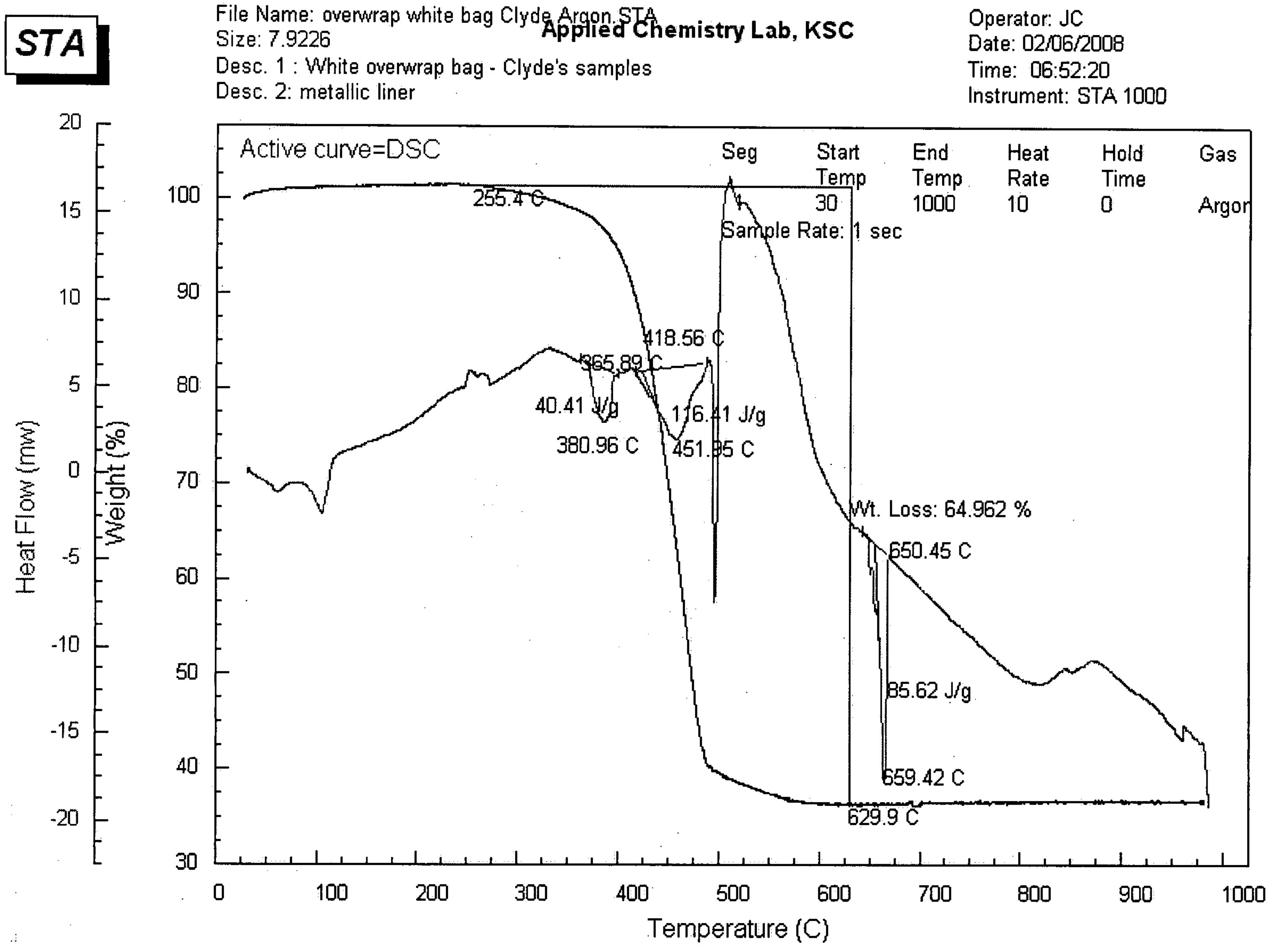
Applied Chemistry Lab, KSC

Operator: JC
Date: 05/09/2007
Time: 13:56:09
Instrument: STA 1000

Seg.	Start Temp	End Temp	Heat Rate	Hold Time	Gas
1	23	1000	10	0	Air

Sample Rate: 1 sec

STA of Overwrap Sample in Argon



File Name: overwrap white bag Clyde Argon.STA
Size: 7.9226
Desc. 1 : White overwrap bag - Clyde's samples
Desc. 2: metallic liner

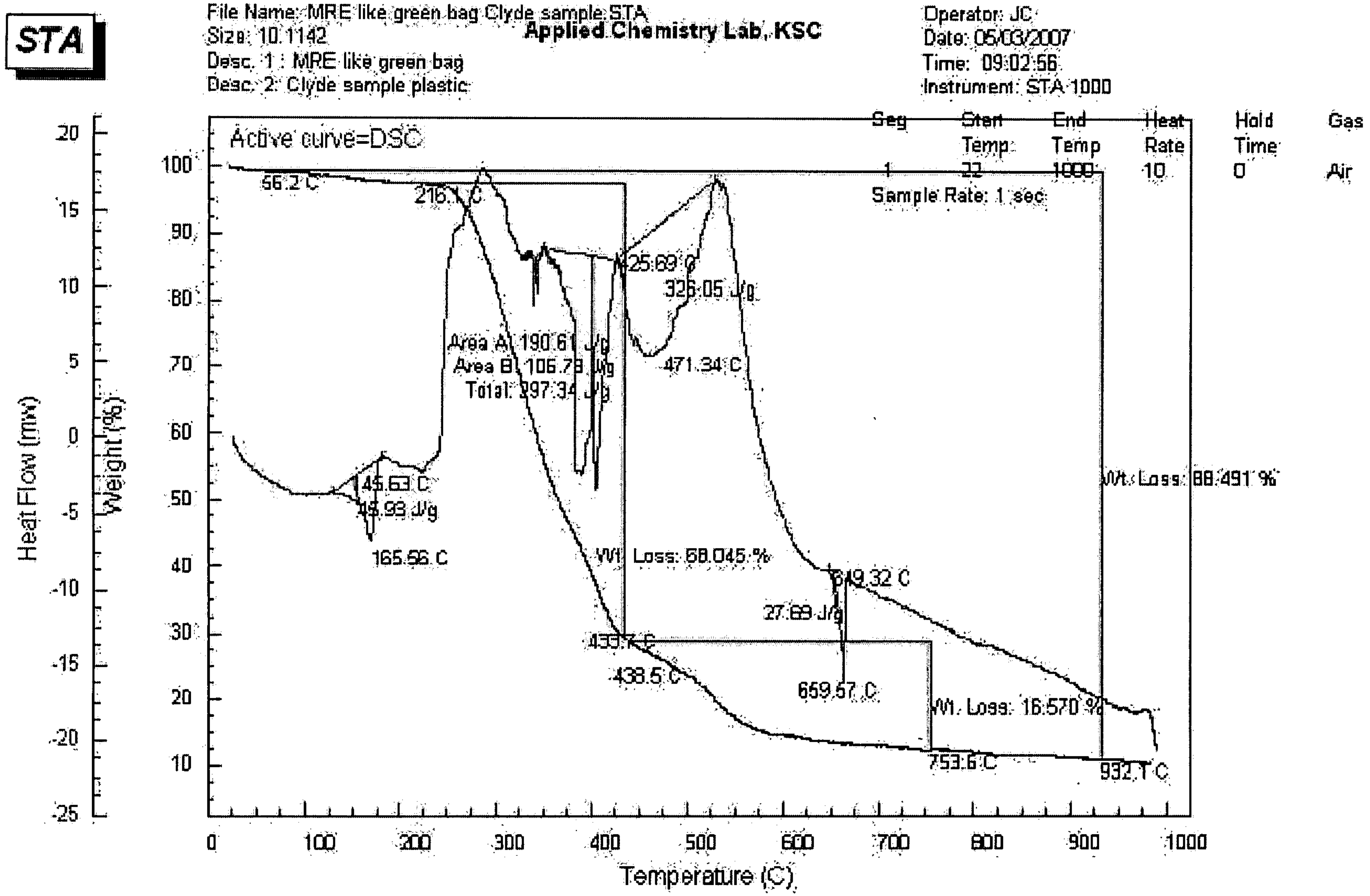
Applied Chemistry Lab, KSC

Operator: JC
Date: 02/06/2008
Time: 06:52:20
Instrument: STA 1000

Seg	Start Temp	End Temp	Heat Rate	Hold Time	Gas
1	30	1000	10	0	Argon

Sample Rate: 1 sec

MRE-like sample bag in air



STA

File Name: MRE like green bag Clyde sample.STA
Size: 10.1142
Desc. 1 : MRE like green bag
Desc. 2: Clyde sample plastic

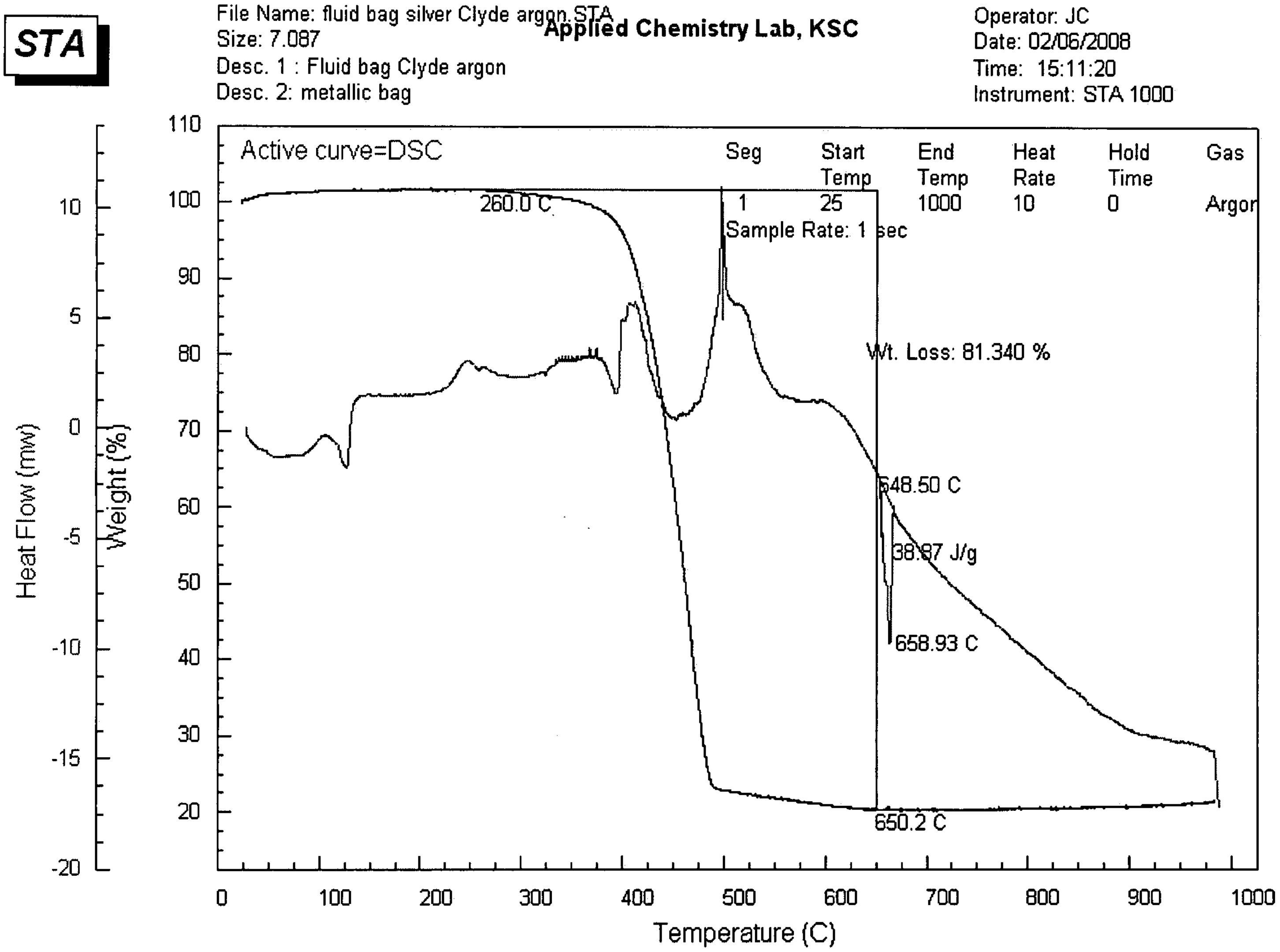
Applied Chemistry Lab, KSC

Operator: JC
Date: 05/03/2007
Time: 09:02:56
Instrument: STA 1000

Seg	Start Temp	End Temp	Heat Rate	Hold Time	Gas
1	22	1000	10	0	Air

Sample Rate: 1 sec

MRE like sample bag in Argon



STA

Applied Chemistry Lab, KSC

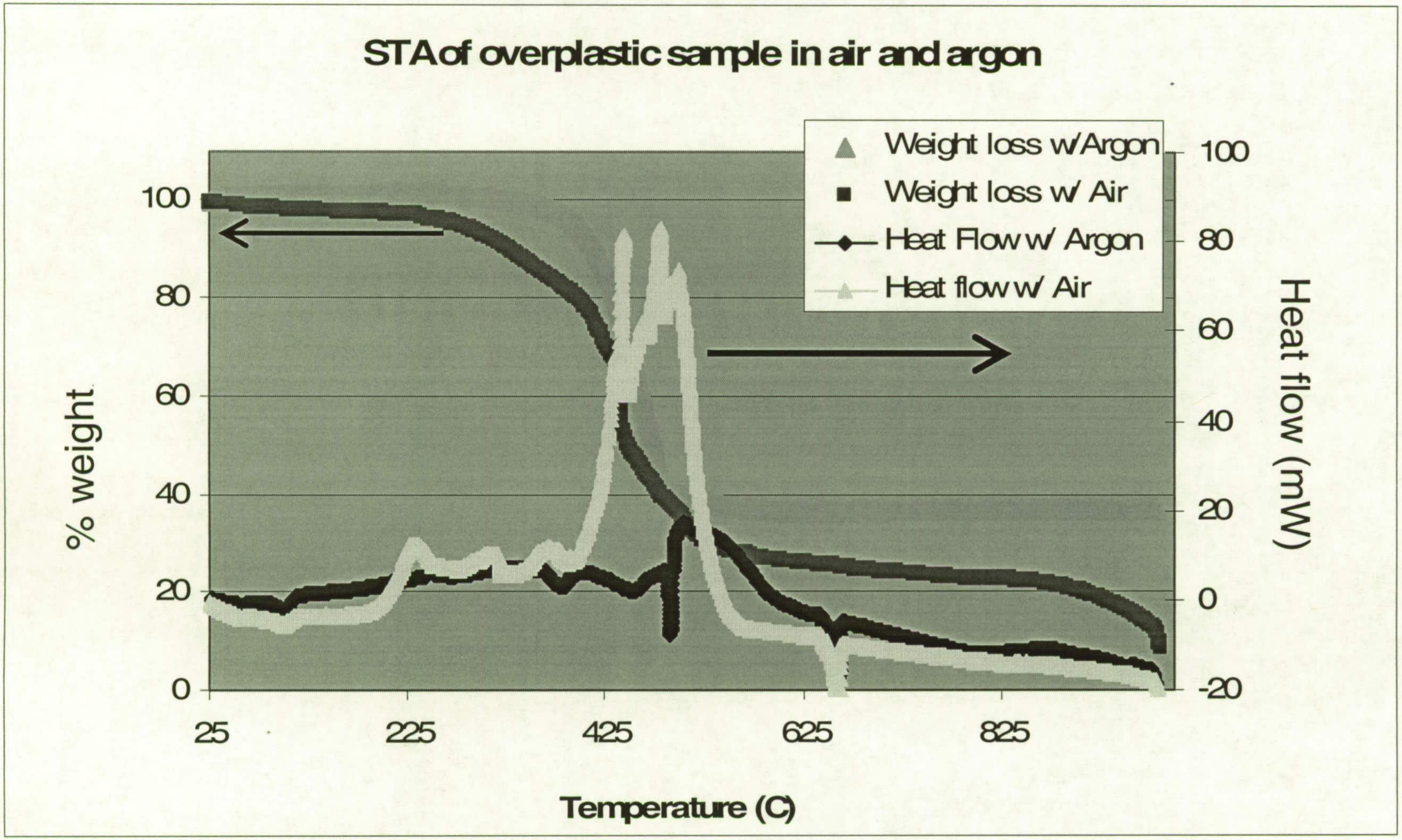
File Name: fluid bag silver Clyde argon.STA
Size: 7.087
Desc. 1 : Fluid bag Clyde argon
Desc. 2: metallic bag

Operator: JC
Date: 02/06/2008
Time: 15:11:20
Instrument: STA 1000

Seg	Start Temp	End Temp	Heat Rate	Hold Time	Gas
1	25	1000	10	0	Argon

Sample Rate: 1 sec

STA of overwrap sample in argon and air atmosphere



Summary of STA of polymers

- Majority of weight loss for all polymers occurs from 200-600 °C
- Pyrolysis at 600 °C will decompose polymers and leave aluminum or aluminum oxide when present in samples (no oxygen will be consumed oxidizing the aluminum)
- Further analysis will determine exact products in different atmospheres

Composition used for estimation of water and methane production

Table VIII Elemental composition of the plastic packaging, human solid, and food wastes attached to plastic packaging expressed as grams on a dry ash-free basis per CM-d

Waste Type	Total Wt	C	H	O	N	S	Al
Plastic Packaging	262.13	162.5	23.23	16.04	4.04	0.000	56.32
Human Solid (dry/ash-free)	28.00	15.71	2.30	8.80	0.86	0.32	0.00
Food Attached to Packaging (dry)	15.03	7.14	0.93	6.40	0.09	0.47	0.00
Total	305.16	185.4	26.46	31.24	5.00	0.79	56.32

- Plastic packaging represents the majority of the waste
- Use values to estimate the oxidation products (assume that process occurs at a temp less than 660 to prevent oxidation of aluminum)

Waste Treatment Options

- Several treatment options could be applied to this production scheme
  - Incineration
  - Pyrolysis/gasification
  - Aerobic biodegradation (long mission durations)
  - Anaerobic biodegradation (long mission durations)
  - Supercritical water oxidation (emerging technology)

Comparison of Processes

- Hydrogen is the limiting resource on the lunar surface (typically less than 100ppm)
- Excess H_2, between 125 and 152 kg, will remain when O_2 tank is empty after power generation in LSAM tanks
- This hydrogen can be used in the Sabatier process for methane production from CO_2 produced in thermal degradation of waste

Water & Methane Production from Trash/Crew Waste

- The moon is poor in carbon and possibly hydrogen (permanently shadowed crater question)
- Plastic trash and crew waste may be a worthwhile in-situ resource (after processing by ECLSS) for water and methane fuel production
  - Currently only 50% of water will be removed from crew waste
- Elemental Composition of Plastic Packaging, Human Solid, and Food Wastes Attached to Pkg (Crew of 4-day)

Waste Type	Total Wt	C	H	O	N	S	Al
Plastic Packaging	1048	650	93	64	16	0	225
Human Solid (dry/ash-free)	111	63	9	35	3	1	0
Food Attached to Packaging (dry)	62	29	4	26	0	3	0
Total per day for Crew of 4 (gms)	1221	742	106	125	19	4	225
Total for Crew of 4 per year (kg)	446	**271**	**39**	46	7	1	82

- Incineration *currently* considered best waste processing approach
  - Low temperature incineration (below 660 C) with subsequent oxidation/methanation of released gas
    - Consumes internal oxygen and hydrogen with carbon (prevents oxidation of aluminum) but leaves behind large amount of solid char (carbon)
  - High temperature incineration with sabatier conversion of carbon dioxide into methane and water

Plastic/Crew Waste Processing at Outpost (Values for Crew of 4)

		In Waste			Added		Waste Gases				Products		50% H_2O In Solids
		C	H	O_2	O_2	H_2	NO	SO_2	CO	Al_2O_3	H_2O	CH_4	
Process 1: Low Temp. Pyrolysis	(per day gm)	741	106	125	759	0	43	6	17	0	932	10	5780
w/ Methanation/Oxidation	**(per year kg)**	**270**	**39**	**46**	**277**	**0**	**16**	**2**	**6**	**0**	**340**	**4**	**2110**
Process 2: High Temperature	(per day gm)	741	106	125	2082	388	43	6	0	426	2225	989	5780
Pyrolysis w/ Sabatier	**(per year kg)**	**270**	**39**	**46**	**760**	**142**	**16**	**2**	**0**	**155**	**812**	**361**	**2110**

- **Conclusion**
  - Low temperature pyrolysis provides some water production benefit but little methane
  - High temperature pyrolysis provides water and methane that could be used for ascent top-off
  - Water remaining in solid waste/trash after ECLSS processing is a significant amount per year

Biodegradeable plastics

- They are currently available
  - Telles (www.metabolix.com) produces a bioplastic family named Mirel™
  - NatureWorks LLC (www.natureworksllc.com) produces plastics used by a variety of companies
- Slight increase in cost should not be an obstacle to this technology application
- Provides alternative method for degradation – microbial organisms which are typically found in terrestrial environments (composting)

Biological production of methane

- Chynoweth et al. and Xu et al. have reported on a 3 stage anaerobic composting system for solid waste treatment expected in an Advanced Life Support System for space habitation
- System is named Sequential Batch Anaerobic Composter (SEBAC)
- Methane production rate averaged 0.3 L CH_4 per gram (dry weight) of volatile solids added

Add ref.

System trades

- Thermal/Chemical system
  - Capable of dealing with current waste stream
  - Power requirements
  - Gas clean up requirements
  - Maintenance
- Biological system
  - Typically slower process
  - Lower power req'ts
  - Require breakdown of current waste or transition to biodegradeable plastics
  - Maintenance
  - Environmental factors

Each system may fit better into specific architectures (mobile vs stationary)

Ongoing work

- Further analysis of biological systems will be performed to determine applicability to lunar missions
- Equivalent system mass (ESM) will be determined for comparison to chemical / thermal systems for production of methane from plastics
  - Mass, volume, consumables, maintenance, etc.

LSAM Power & Hydrogen Scavenging for Water Production

- The total recoverable mass varies between 132 and 801 kg for the oxygen system and 141 and 252 kg for the hydrogen system
  - Exact amount of unusable propellants will vary on the detailed design of the feed system
- The amount of recoverable propellants will vary from mission to mission depending on the reserves used

	LOX		LH2
Usable Propellant	20891	kg	3482
Nominal	20222	kg	3371
Reserve	669	kg	111
Unusable Propellant			
Residual Vapor	2.23	kg	100.2
Residual Liquid	211.0	kg	54.5
Unrecoverable Mass			
Feedline Liquid	33.69	kg	5.67
Low Pressure Vapor	47	kg	8.27
Total Recoverable Mass			
Minimum	132.1	kg	140.8
Maximum	800.6	kg	252.2

- For unshielded tanks in view of the sun
  - Estimated O_2 boiloff rate is 388 g/hr and H_2 boiloff rate is 503 g/hr
  - Boil off rates can be reduced if the remaining residuals can be transferred into a single storage tank and that tank is not in view of the sun
    - Oxygen boil off reduces to 67 g/hr and Hydrogen boil off reduces to 46.7 g/hr
    - O_2 loss is minimal and H_2 loss is between 5 kg and 67 kg, depending on the ullage temperature.
- Current estimates of fuel cell use rates are 1600 g/hr oxygen and 200 g/hr hydrogen (82 hours to 500 hours of operation) at 4 kW
  - LSAM oxygen will be entirely consumed first.
  - **Excess H_2, between 125 and 152 kg, will remain when O_2 tank is empty after power generation**
- **Significant amount of water can be made** for fuel cell power, ECLSS, EVA, and radiation shielding from *each mission*

Water from Fuel Cell　　Water from ISRU O_2

LSAM Residual		Water Made	Residual H_2 Needed	Extra H_2	In-Situ O_2	Extra Water	Total Water
O_2	H_2						
132	141	**149**	17	125	996	**1121**	**1269**
801	252	**901**	100	152	1215	**1367**	**2268**

➢ **Large volume and mass associated with H_2 gaseous storage concludes that best method of H_2 recovery is to convert quickly to water with In-situ oxygen**