Long-Term Nitrogen Management in Bioreactor Landfills

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Introduction

- Landfill leachate contains elevated concentrations of ammonia (NH_3-N) after BOD and COD are reduced
- High concentrations of NH_3-N may require very long-term leachate treatment

Strategies for Ammonia Removal

- Ex-situ nitrification ($NH_3 \rightarrow NO_3^-$)
- In-situ denitrification

$$24NO_3^- + 5C_6H_{12}O_6 + 24H^+ \rightarrow 12N_2 + 42H_2O + 30CO_2$$

Project Objectives

- Increased understanding of reactions controlling the loss of nitrate in a landfill
  - support a field-scale project in Kentucky, USA

Project Questions

- How much nitrate can be added safely?
- Is there an inhibitory pH increase?

$$24NO_3^- + 5C_6H_{12}O_6 + 24H^+ \rightarrow 12N_2 + 42H_2O + 30CO_2$$

- Can well decomposed refuse consume nitrate?

Project Questions

- Can nitrate addition lead to NH_4 production?
  - Dissimilatory Nitrate Reduction to Ammonium

$$3NO_3^- + C_6H_{12}O_6 + 6H^+ \rightarrow 3NH_4^+ + 6CO_2 + 3H_2O$$

$$NO_3 \rightarrow N_2 + 5e^-$$

$$NO_3 \rightarrow NH_4^+ + 8e^-$$

- How do denitrifier populations change with time during refuse decomposition?

Experimental Program: Part 1

- Laboratory scale - highly controlled
- Monitored shredded residential refuse in 10-liter reactors (9)
- Inoculated with well-decomposed refuse
- Recycled leachate to accelerate decomposition

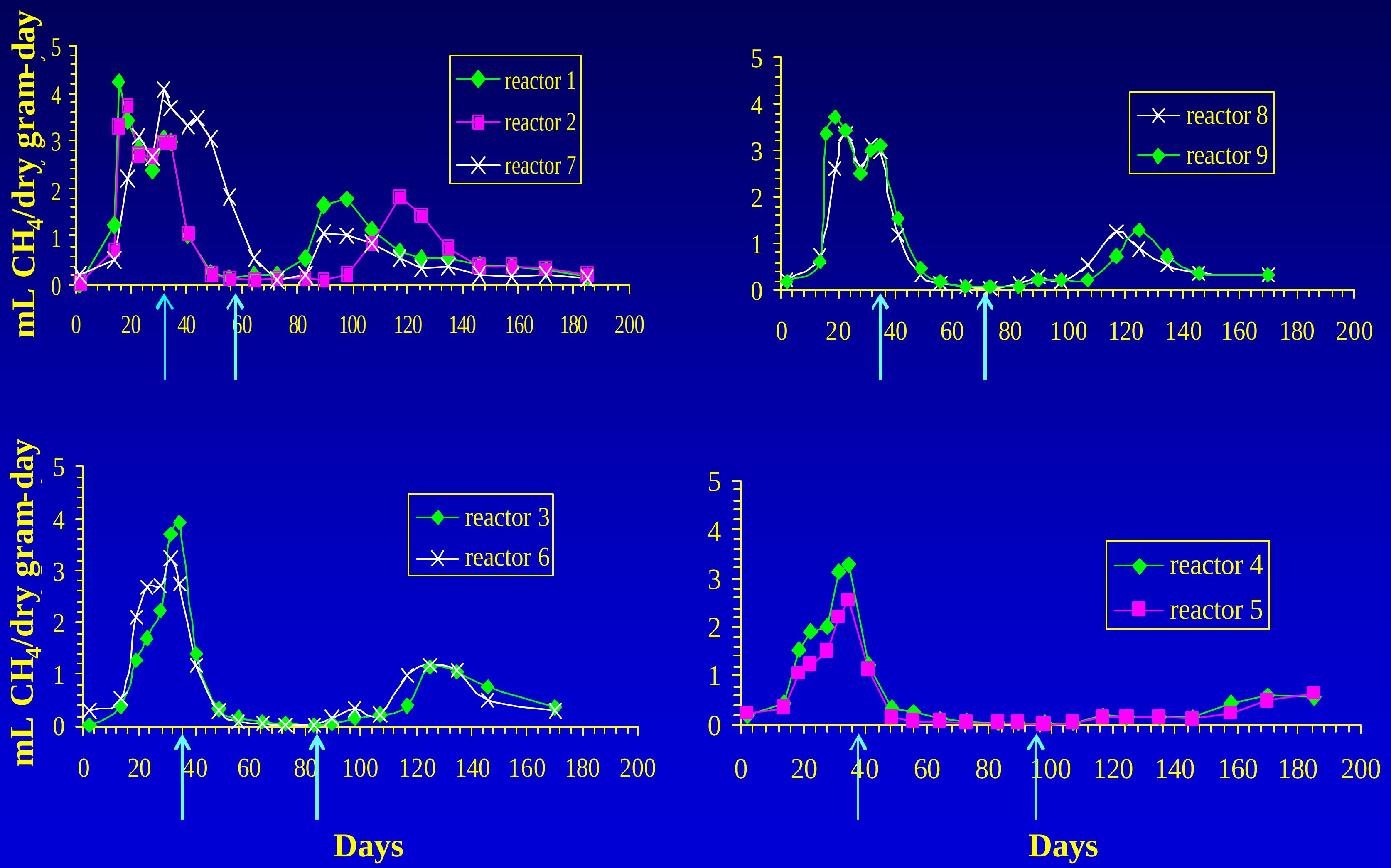
Experimental Program: Part I

- Nitrate added to 8 of 9 reactors to study effect of nitrate addition on:
  - methane production, inhibition and recovery
  - nitrate depletion
  - pH
  - N_2O production

Nitrate Additions

Reactor	Day of Initial NO_3 Addition	Day of Final Addition
1	36	55
2	36	55
8	36	71
9	36	71
3	36	81
6	36	81
4	36	95
5	36	95
7*	59	67

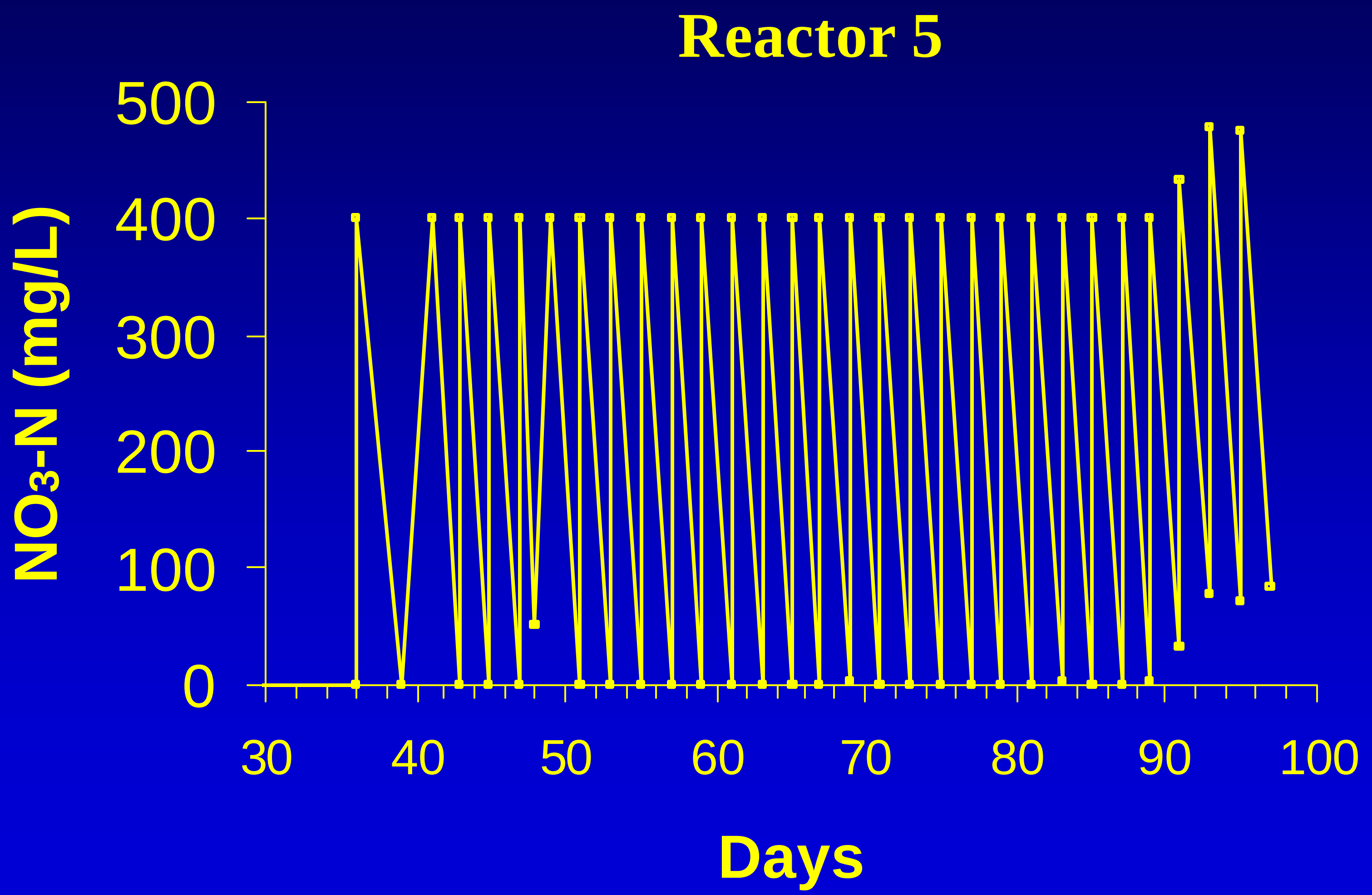
Methane Production

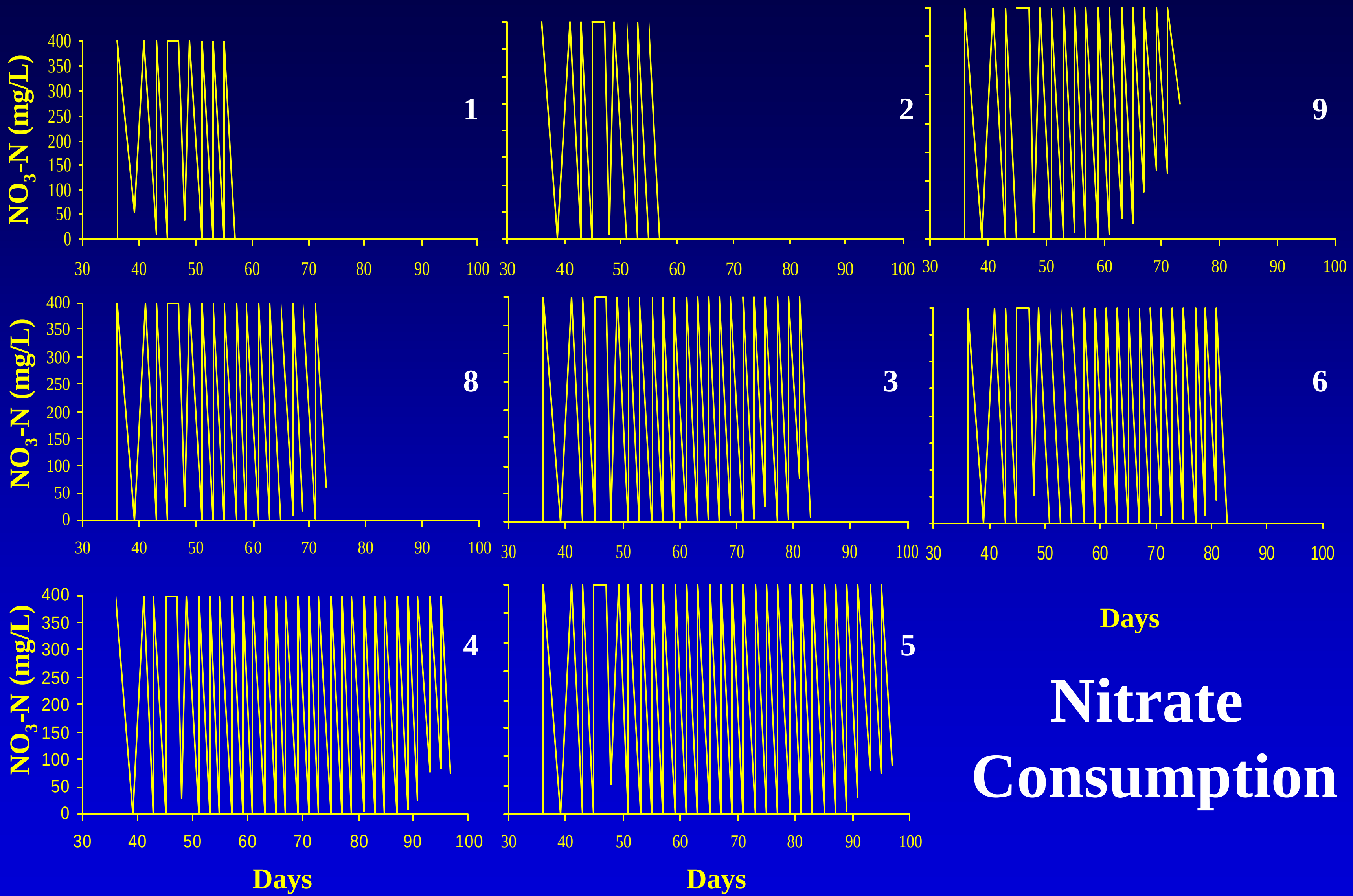


Inhibition of Methane Production

Reactor	# of Nitrate Additions	Methane Production Recovery Time (days)
1	9	28
2	9	52
8	18	36
9	18	46
3	22	44
6	22	36
4	29	63
5	29	63
7	5	23

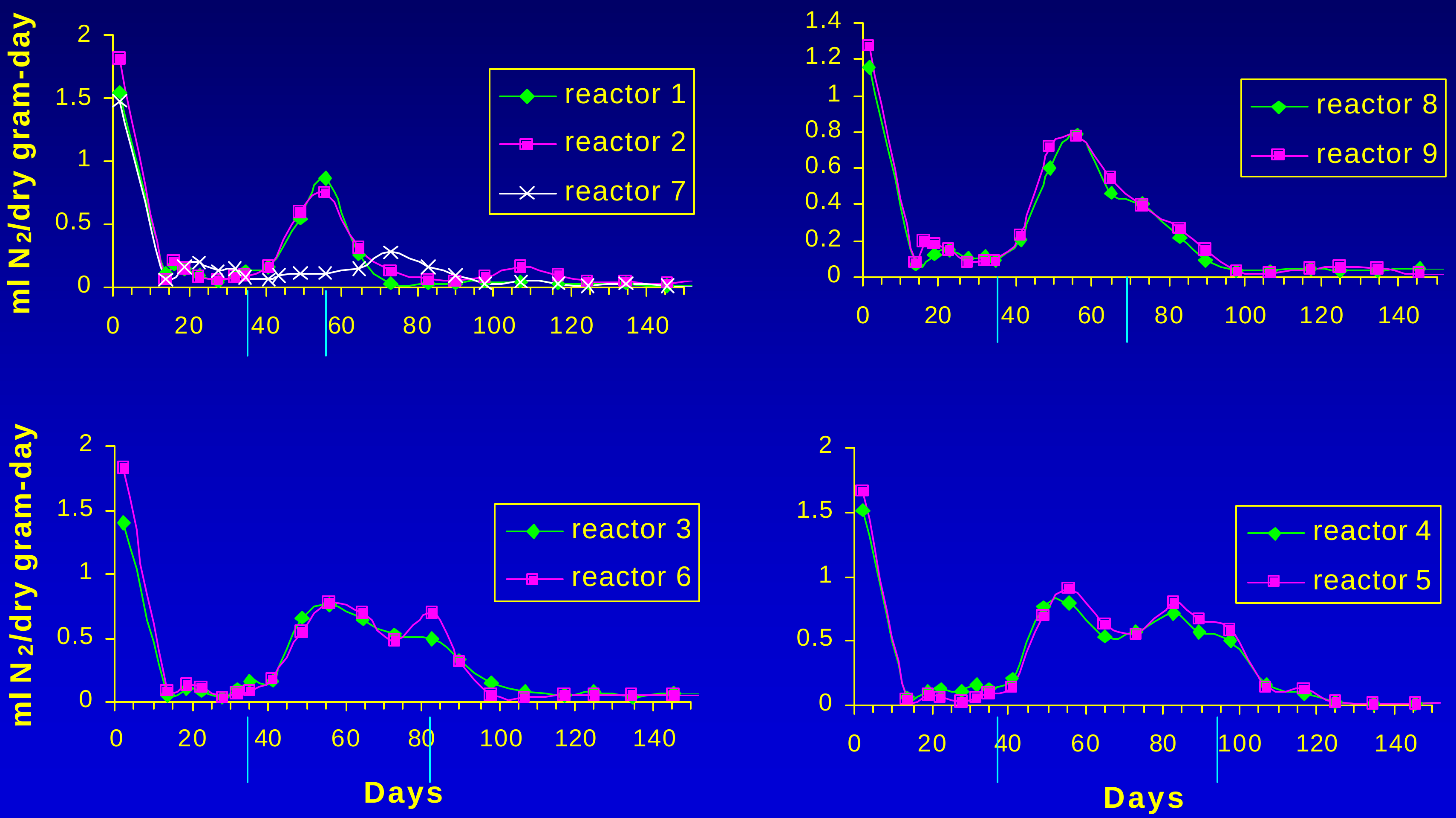
Nitrate Consumption



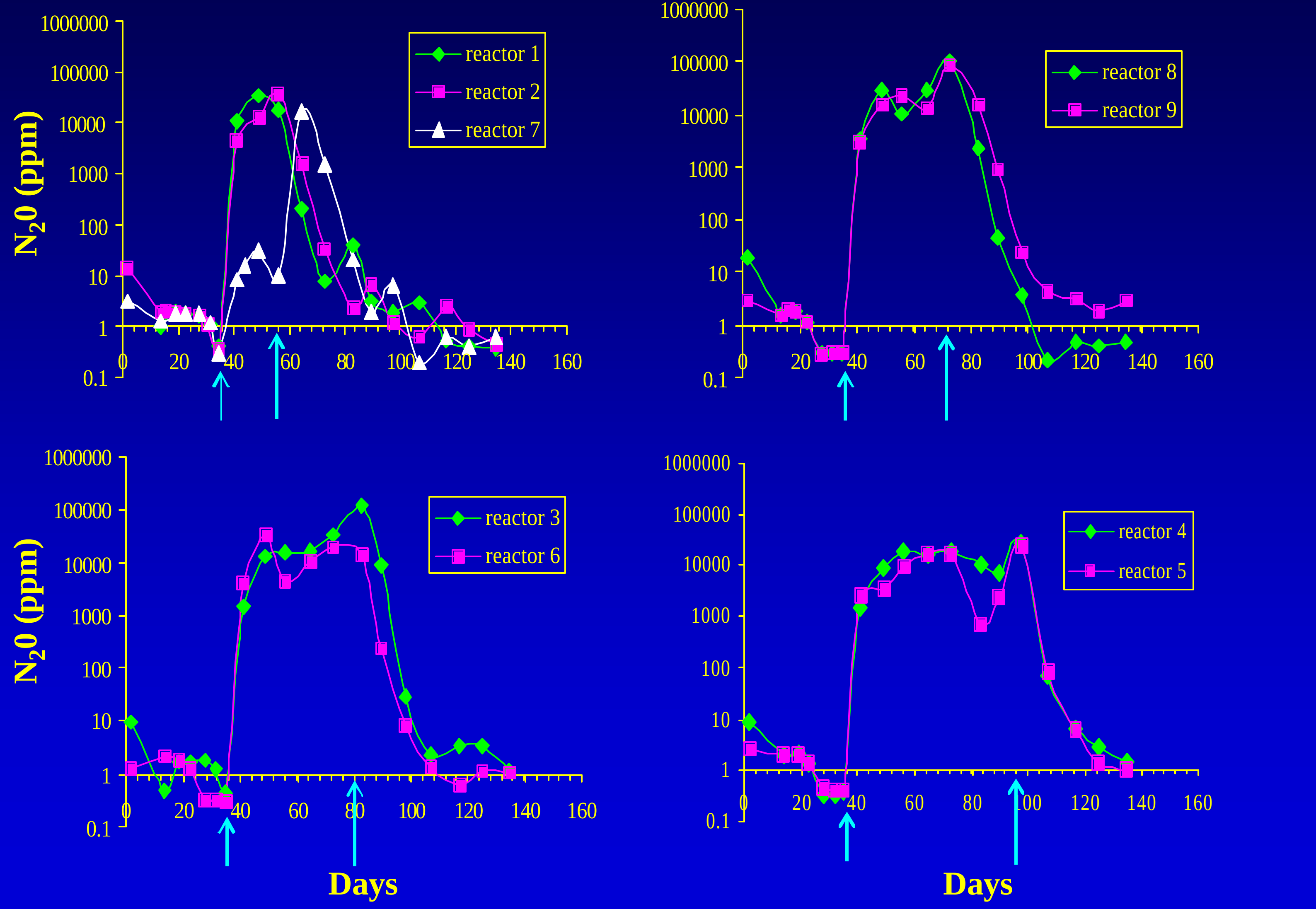


Nitrate Consumption

Nitrogen Production



Nitrous Oxide Production

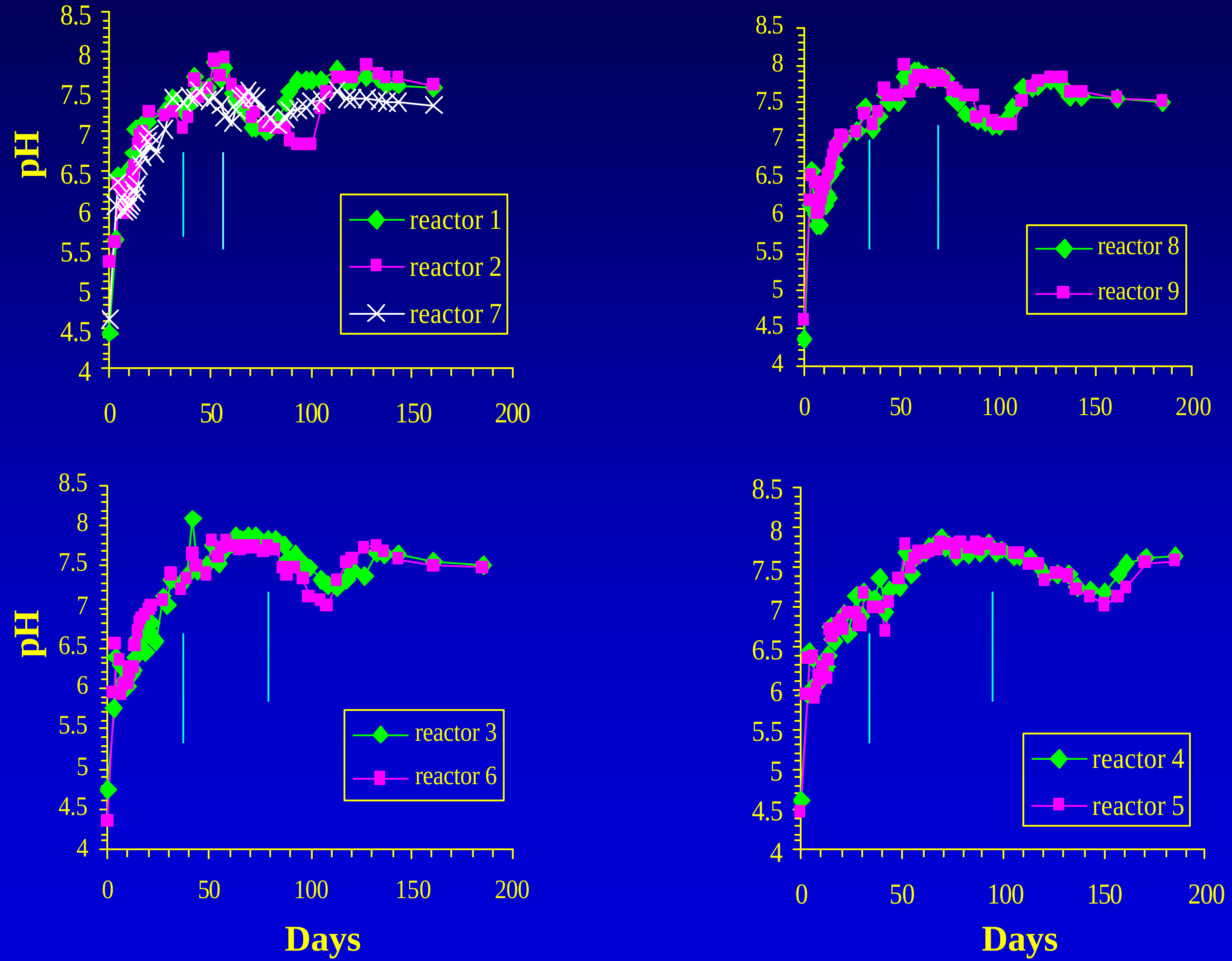


Production of N_2O: Greenhouse Gas

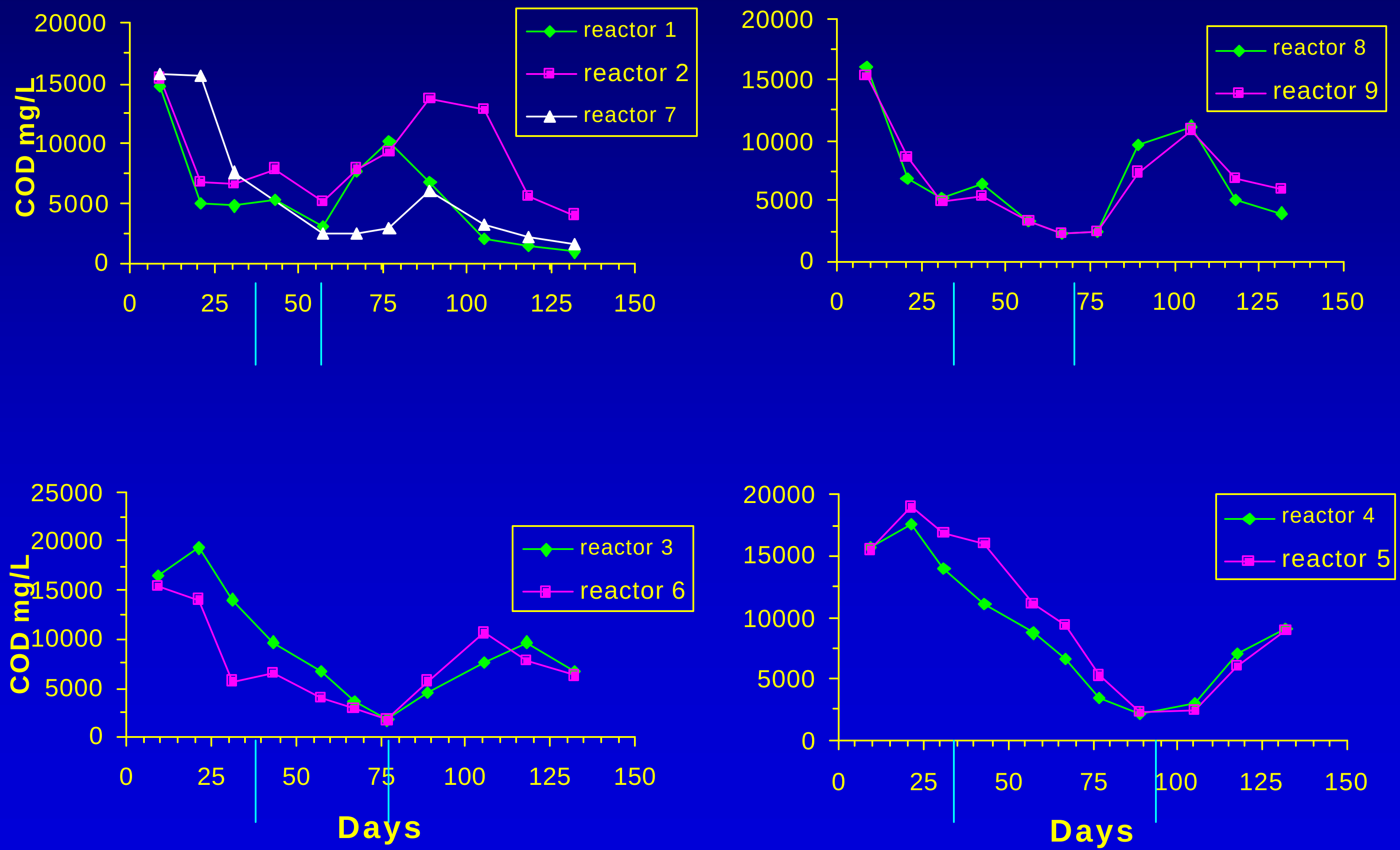
Reactor	Mass of NO_3-N added (grams)	Total N_2O mass (grams)	N_2O-N/NO_3-N (%)
1	20.99	2.26	6.8%
2	20.84	1.58	4.8%
3	50.07	4.84	6.2%
4	67.69	2.95	2.8%
5	67.37	1.88	1.8%
6	49.10	2.69	3.5%
8	38.90	3.72	6.1%
9	38.49	3.31	5.5%

- Average: 4.5%
- Likely a worst case for N_2O production

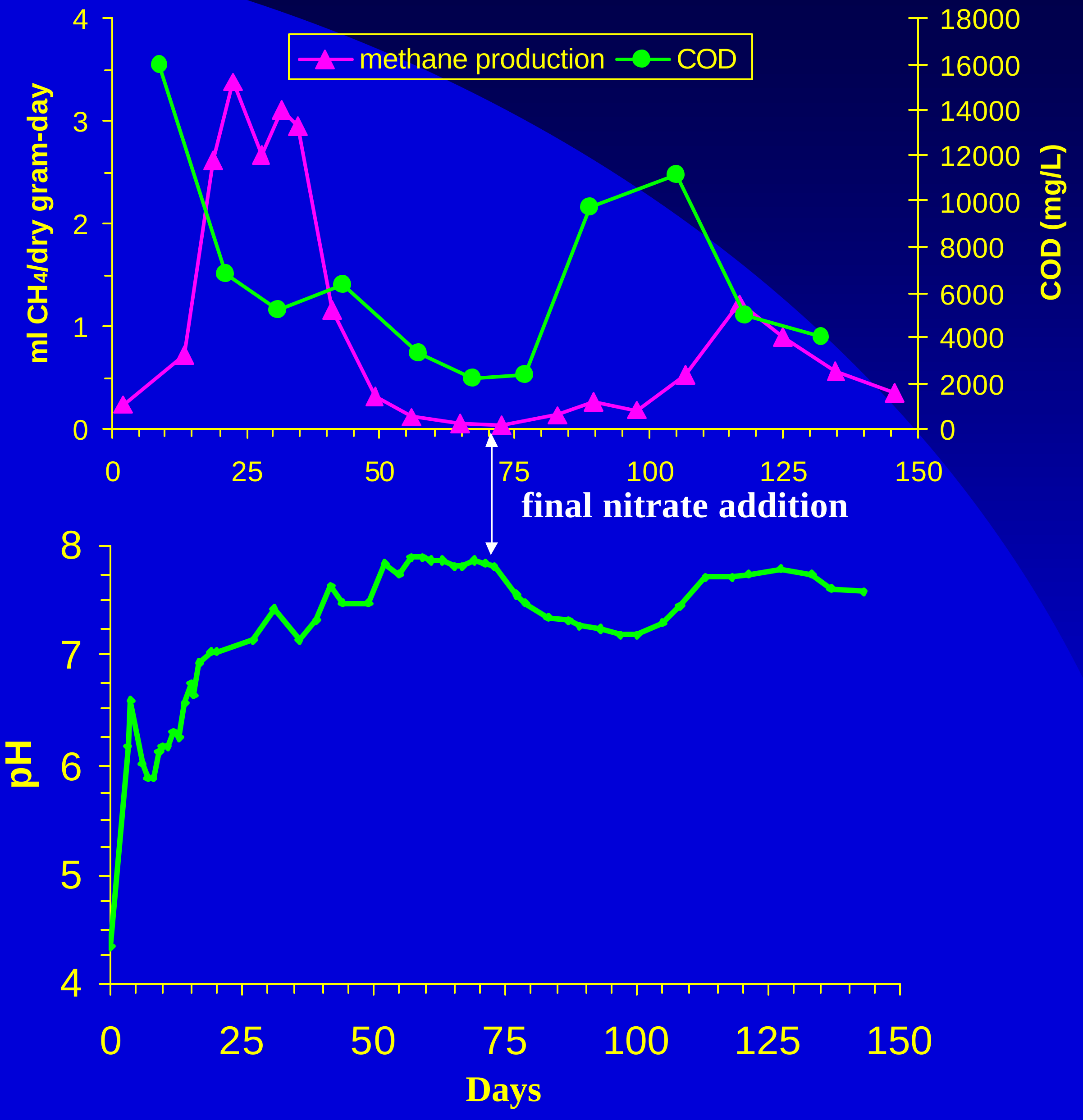
pH


pH
8.5
8
7.5
7
6.5
6
5.5
5
4.5
4
0
50
100
150
200
reactor 1
reactor 2
reactor 7
reactor 8
reactor 9
reactor 3
reactor 6
reactor 4
reactor 5
Days
Days

COD Concentrations



Reactor 8

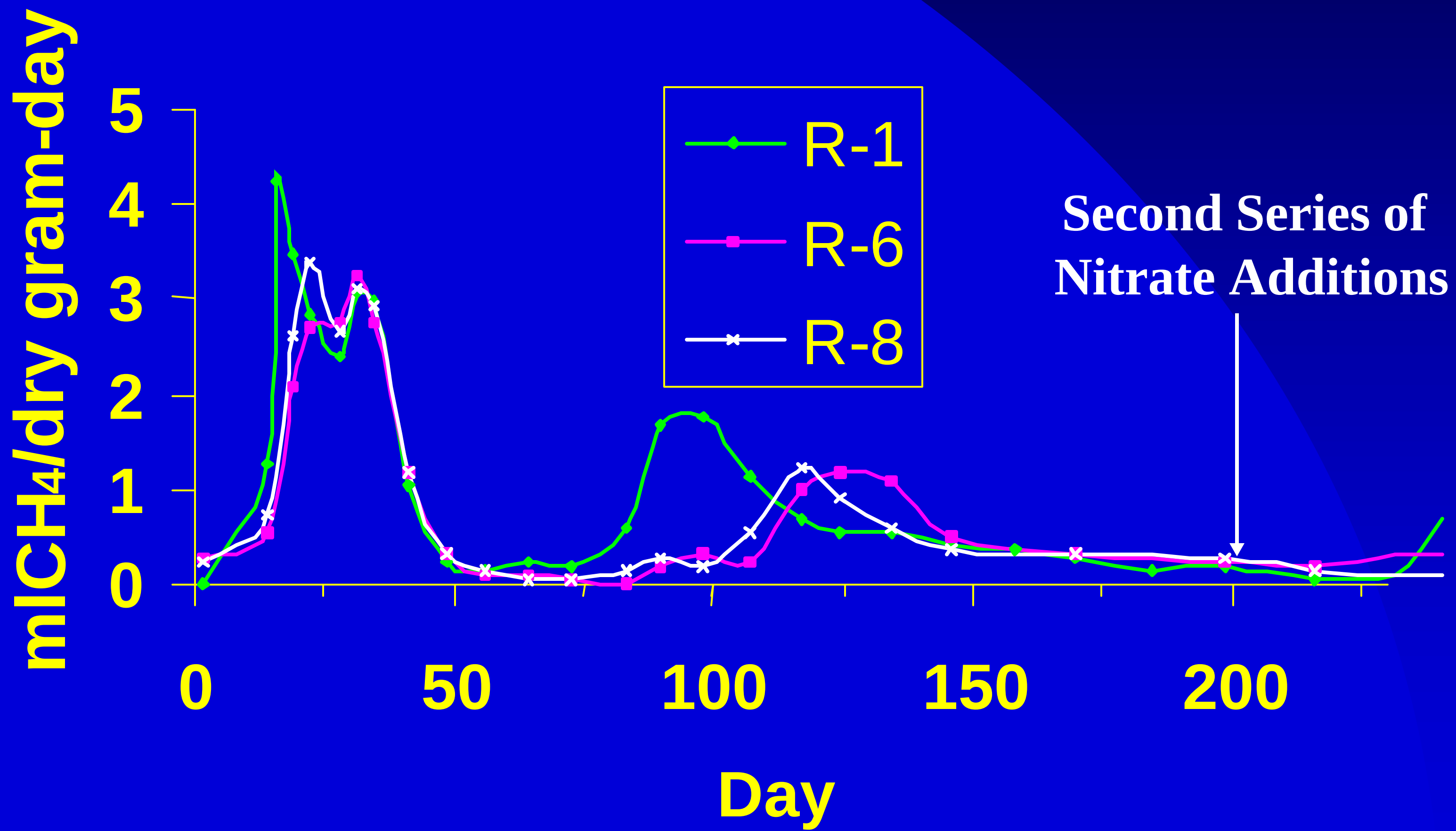


methane production
COD
ml CH4/dry gram-day
COD (mg/L)
4
3
2
1
0
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
25
50
75
100
125
150
final nitrate addition
pH
8
7
6
5
4
0
25
50
75
100
125
150
Days

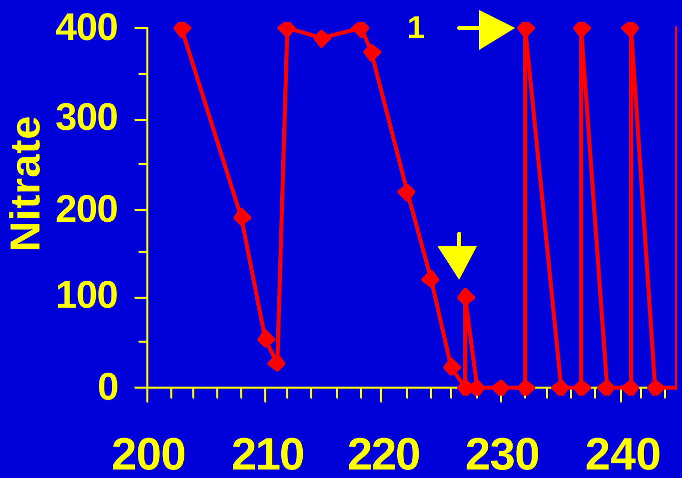
Experimental Program: Part II

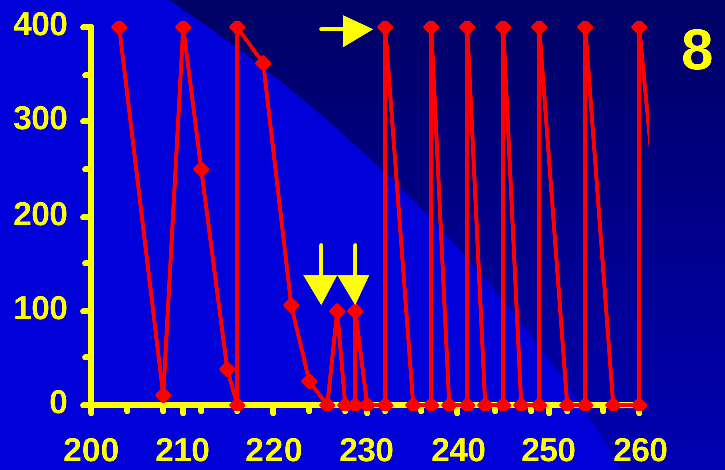
- Evaluate NO_3 depletion and NH_3 production in well decomposed refuse.
- Evaluate response of added organic carbon
  - acetate
  - humic acids
  - fresh refuse
- Nitrate was added to 3 of 9 reactors (1, 6, & 8)

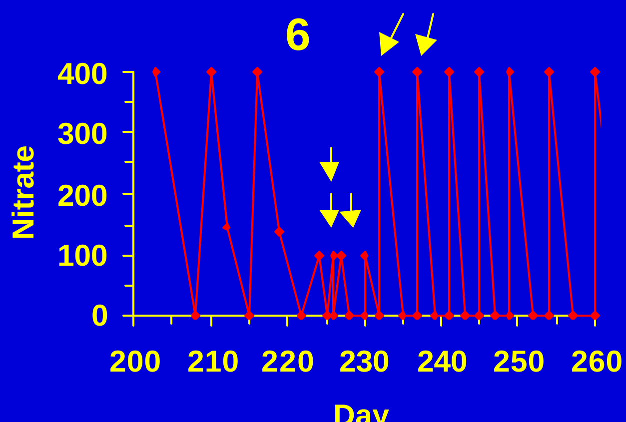
Well Decomposed Refuse



Nitrate Depletion in Decomposed Refuse

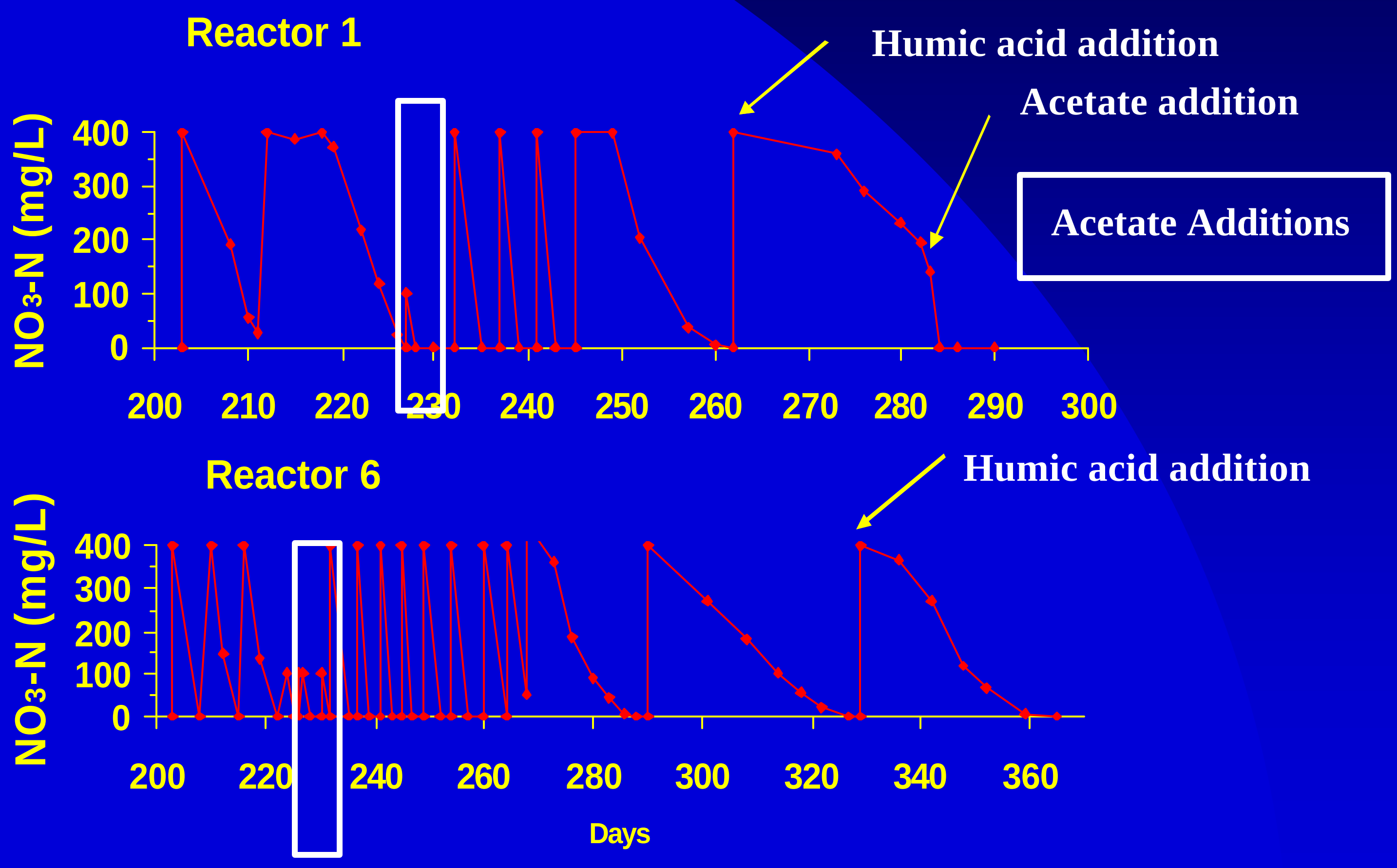




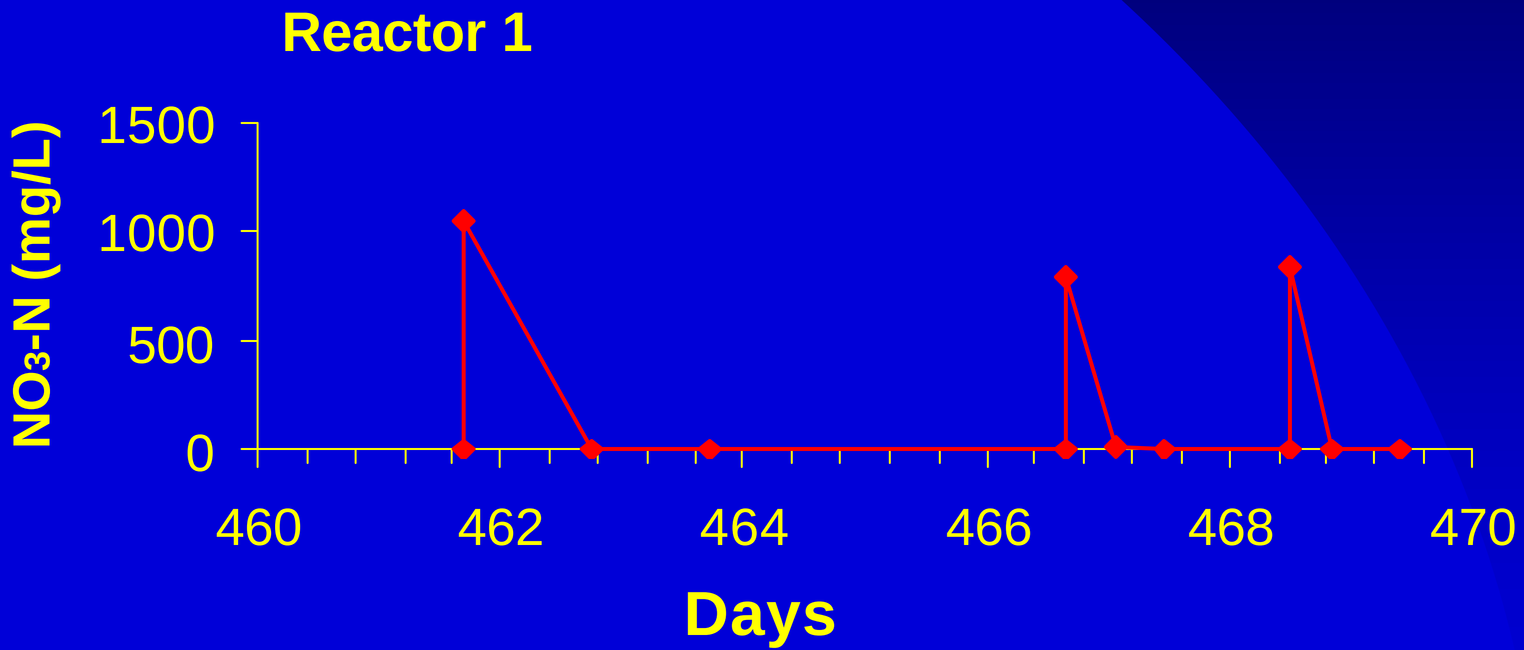


Acetate addition at 5 times stoichiometric

Humic Acid Addition



Addition of Fresh Refuse



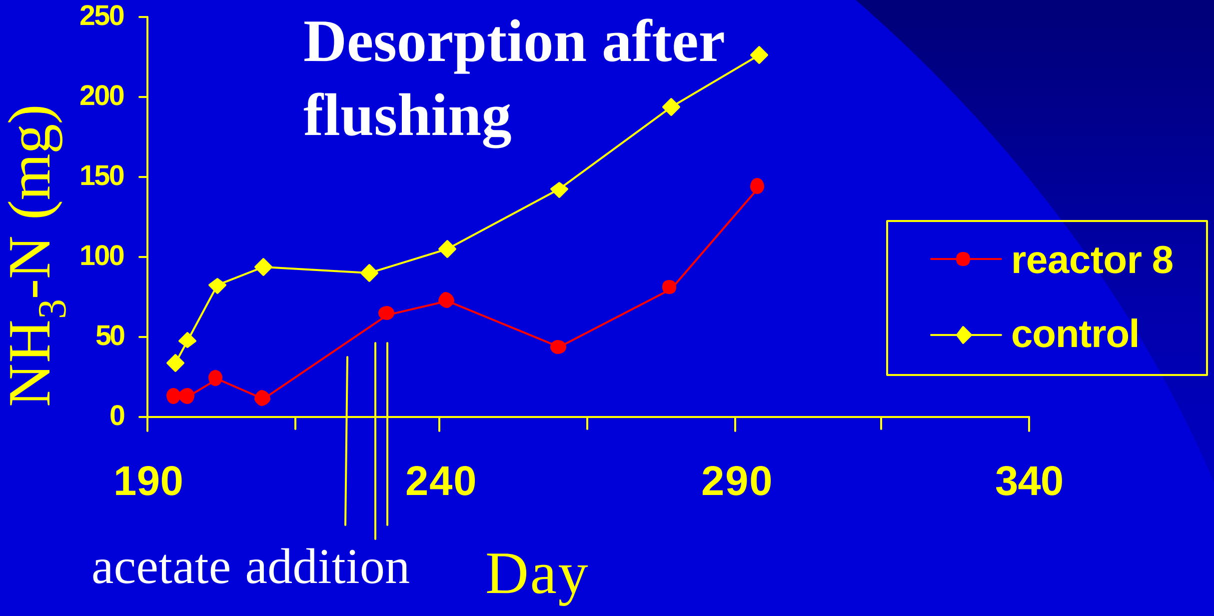
Nitrate depleted within 24 hours

Might the Refuse Ecosystem Produce Ammonia?

- Once the denitrification potential was reduced, high concentrations of degradable organic carbon were added

$3NO_3^- + C_6H_{12}O_6 + 6H^+ \rightarrow \mathbf{3NH_4^+} + 6CO_2 + 3H_2O$

Ammonia Production

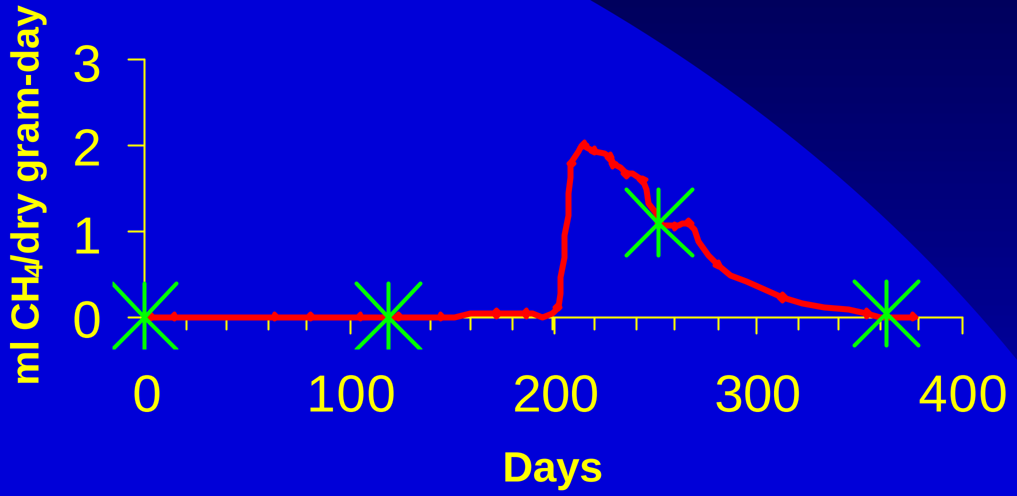


Theoretical increase in NH_3-N, based on DNRA, is 3160 mg NH_3-N

Experimental Program Part III

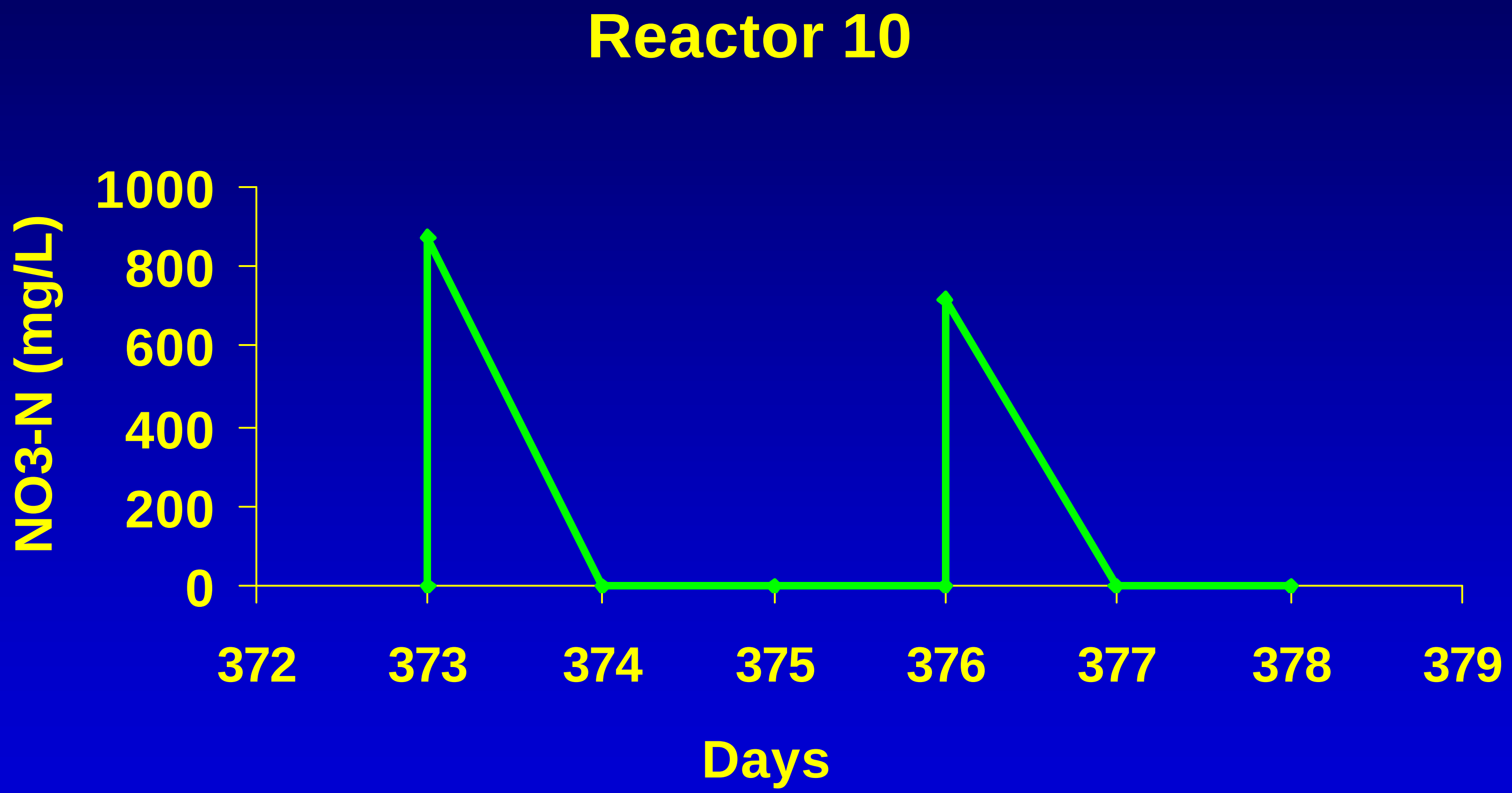
- Monitored shredded residential refuse in 10-liter reactors (4) without the use of any seed
- Solids periodically removed from one reactor for enumeration of the total anaerobic and denitrifying bacteria populations (MPN)

Denitrifier Populations



MPN Population (cells/dry gram)		
Day	**Total Anaerobes**	**Denitrifiers**
0	**$6.2*10^8$**	**$2.7*10^8$**
121	**$1.8*10^7$**	**$8.7*10^3$**
252	**$> 6.2*10^9$**	**$1.6*10^3$**
364	**$4.8*10^9$**	**$7.5*10^3$**

Nitrate Depletion



Nitrate depleted within 24 hours

Conclusions

- Decomposing refuse has excellent capability to convert nitrates to N_2 gas
- The methane-producing bacteria recover once nitrate addition stops
- Given rapid nitrate consumption capacity, full-scale effects are likely near the point of addition

Conclusions

- Denitrification reactions did not adversely affect refuse pH
- Well-decomposed refuse does have the ability to consume nitrate, although it is much slower than decomposing refuse
- The addition of high concentrations of degradable organic carbon did not lead to ammonia production

Conclusions

- It would appear that the use of a landfill as a bioreactor in which nitrate-rich leachate is recirculated for conversion to N_2 gas is viable, and denitrification will not adversely upset the landfill ecosystem in a manner from which it cannot recover

Session Issues

- What do we need to know about leachate quality
  - pretty well defined, quantity is major question
  - the time required for treatment and treatment levels will be a function of receiving body & leachate quantity
  - non-paper degradable organic waste (food/green/special) wastes likely to have most impact on leachate composition
  - nutrient limitations?