LOW SUBSTRATE NITRATE KINETICS UTILIZING PASSIVE SELF-REGULATING DENITRIFICATION TECHNOLOGY

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Introduction

Increased Density + Higher Nitrates

- Nitrate Toxicity (Marine Systems)
- Nitrate – Environmental Impact

Change thinking from conversion of nitrogen to removal of nitrogen!

Denitrification

Engineering Overview

- Fundamentals of Denitrification
  - Stoichiometry & Kinetics
- Tertiary Denitrification
  - Exogenous electron donor
- One-sludge Denitrification
- Other Options

Denitrification

(Bacteria widespread in the environment)

- Facultative aerobic bacteria
  - Shift to NO_3^- or NO_2^- when O_2 limited
- Chemotrophic
  - Heterotrophic – organic electron donor
  - Autotrophic – H_2 or reduced sulfur

Heterotrophic Denitrification

- Low BOD treated wastewater – external carbon source
  - methanol, acetate, glucose, ethanol, starch – cheap, bulk quantities
- High BOD wastewater – endogenous respiration

Denitrification

Nitrate (NO_3^-) ⇒ Nitrite (NO_2^-) ⇒ Nitric Oxide (NO) ⇒ Nitrous Oxide (N_2) ⇒ Nitrogen Gas (N_2)

$$NO_3 + \frac{5}{6} CH_3OH \rightarrow \frac{1}{2} N_2 + \frac{5}{6} CO_2 + \frac{2}{3} H_2O + OH^-$$

Denitrification

Optimal Conditions

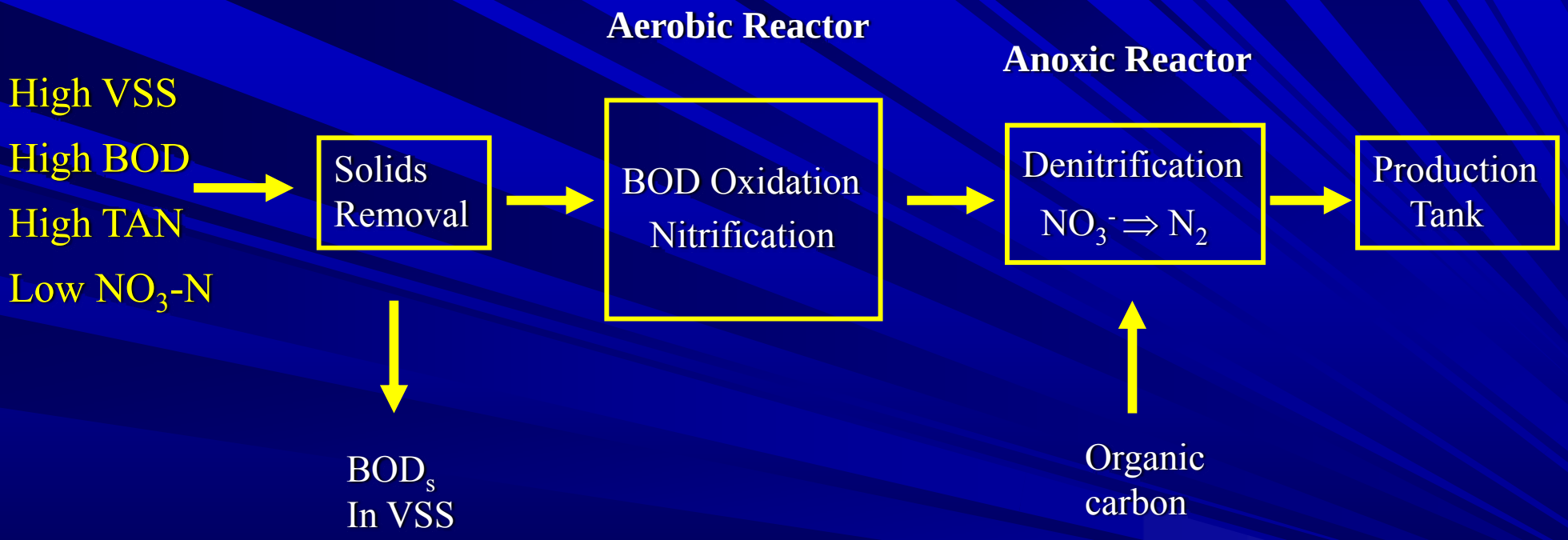
- Low redox potential
  - ORP > -200 mV incomplete denitrification NO_2^-, NO_2 and N_2O
  - ORP < 400 mV production of hydrogen sulfide (H_2S)
- Low Oxygen Levels (anoxic)
  - High DO $\Rightarrow$ accumulation of intermediates, NO_2^-, NO_2 and N_2O
- pH: 7 to 8
- Alkalinity 3.57 g $CaCO_3$/ g NO_3^-N consumed

Denitrification Classifications

Wastewater Treatment Industry

- Tertiary – external carbon source
  - methanol, acetate, glucose, ethanol, starch – cheap, bulk quantities
- One-sludge / single sludge - BOD

Tertiary Treatment



Tertiary Treatment

- Organic donors ⇒ heterotrophic denitrification
  - "Methanol" – historical, cheap, readily available

$$NO_3^- + 1.07\ CH_3OH + H^+ \Rightarrow 0.061\ C_4H_7O_2N + N_2 + 2.42\ H_2O + 0.76\ CO_2$$

- Inorganic donors ⇒ autotrophic denitrification
  - hydrogen gas – H_2

$$H_2 + 0.35\ NO_3^- + 0.05\ CO_2 + 0.35\ H^+ \Rightarrow 0.01\ C_4H_7O_2N + 0.17\ N_2 + 1.14\ H_2O$$

  - Reduced sulfur – SO_4^{2-}

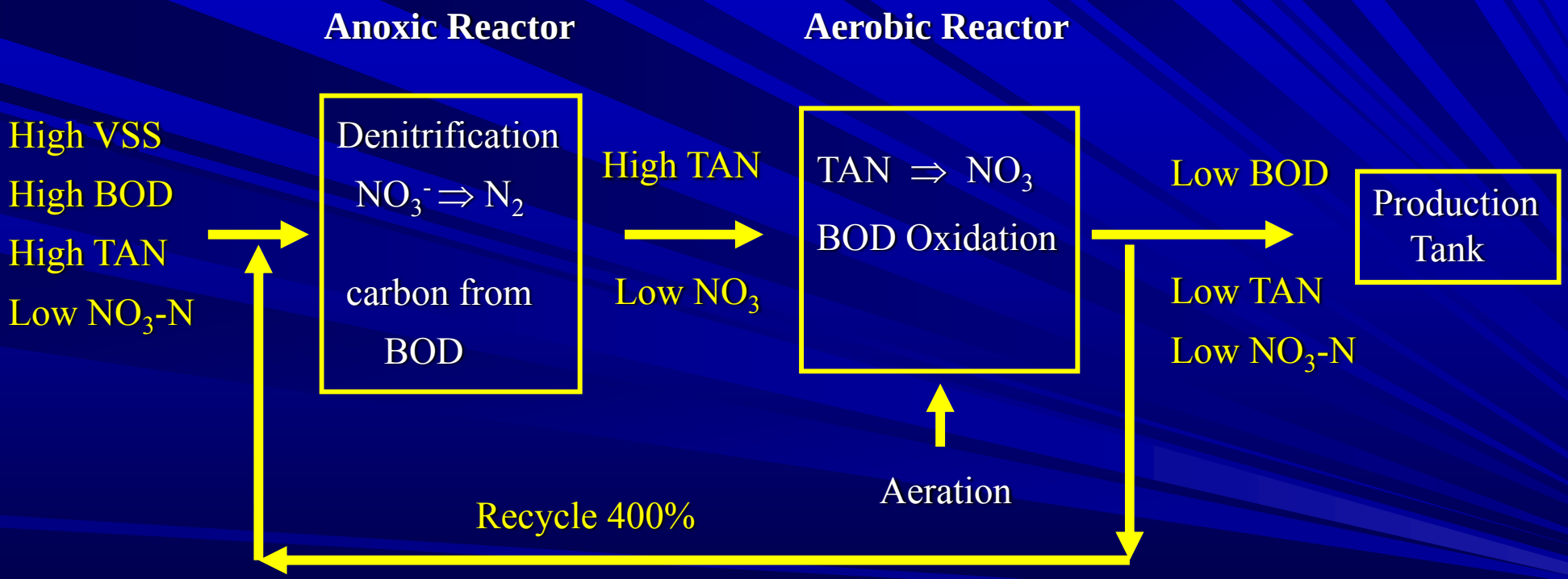
$$S + 1.2\ NO_3^- + 0.4\ H_2O \Rightarrow SO_4^{2-} + 0.60\ N_2 + 0.80\ H^+$$

Tertiary Treatment

- Activated Sludge
  - SRT = 5 days
  - 0.75 g VSS/g NO_3-N removed
- Biofilms
  - Submerged Fixed Films
  - Fluidized Media
  - MBBR
  - Membrane Bioreactors

Single-sludge Denitrification

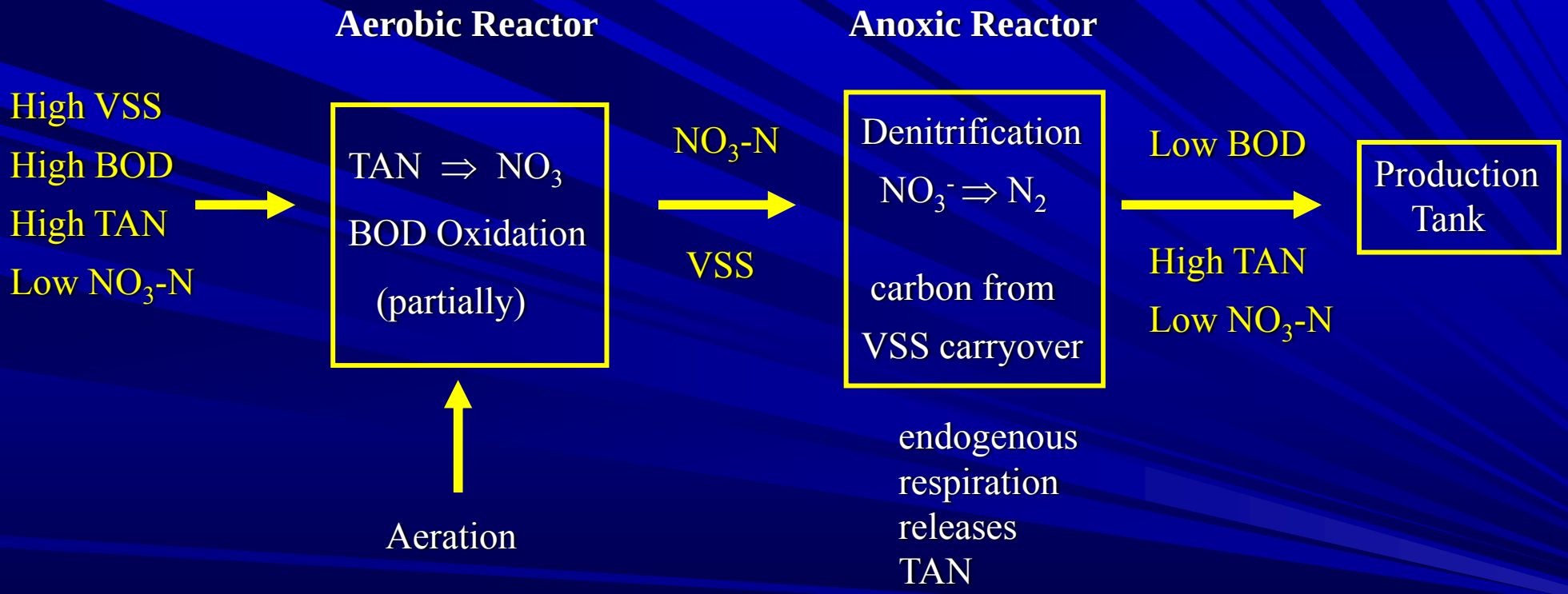
(preanoxic denitrification)



Advantages: direct use of influent BOD, faster kinetics, low TAN discharge

Single-sludge Denitrification

(biomass storage & decay or postanoxic denitrification)



Problems: slow kinetics of endogenous respiration, release of TAN from decaying sludge

Single-sludge Denitrification

- BOD supplies organic carbon source
- Integrated into biofilter
  - Aerobic: oxidation of BOD & nitrification
  - Anoxic: denitrification
- Advantages
  - No chemicals – reduces cost, danger of under /overdosing
  - BOD removed as part of denitrification process
  - High percentage of nitrogen removed

AST Research Areas

preanoxic denitrification –single sludge

PolyGeyser® Bead Filter

postanoxic denitrification – Tertiary treatment

PolyGeyser® Bead Filter

DOC/NOAA Phase I SBIR

Concurrent Clarification and Biological Nitrification/Denitrification in a Single Floating Bead Bioclarifier to Simplify Nitrogen Management in Recirculating Aquaculture Systems

Phase I Technical Objectives

Characterize the volumetric denitrification capacity, using captured solids, in AST's drop filter configuration

Determine the effects of the sludge retention time and backwash frequency on the denitrification process within these filters

Conduct basic reactor modeling to project PolyGeyser denitrification performances for a variety of applications

PolyGeyser® Bead Filter

preanoxic denitrification

Aerobic Reactor

High BOD
High TAN
Low NO_3-N

→

TAN ⇒ NO_3
BOD Oxidation

→

Low BOD
Low TAN
Low NO_3-N

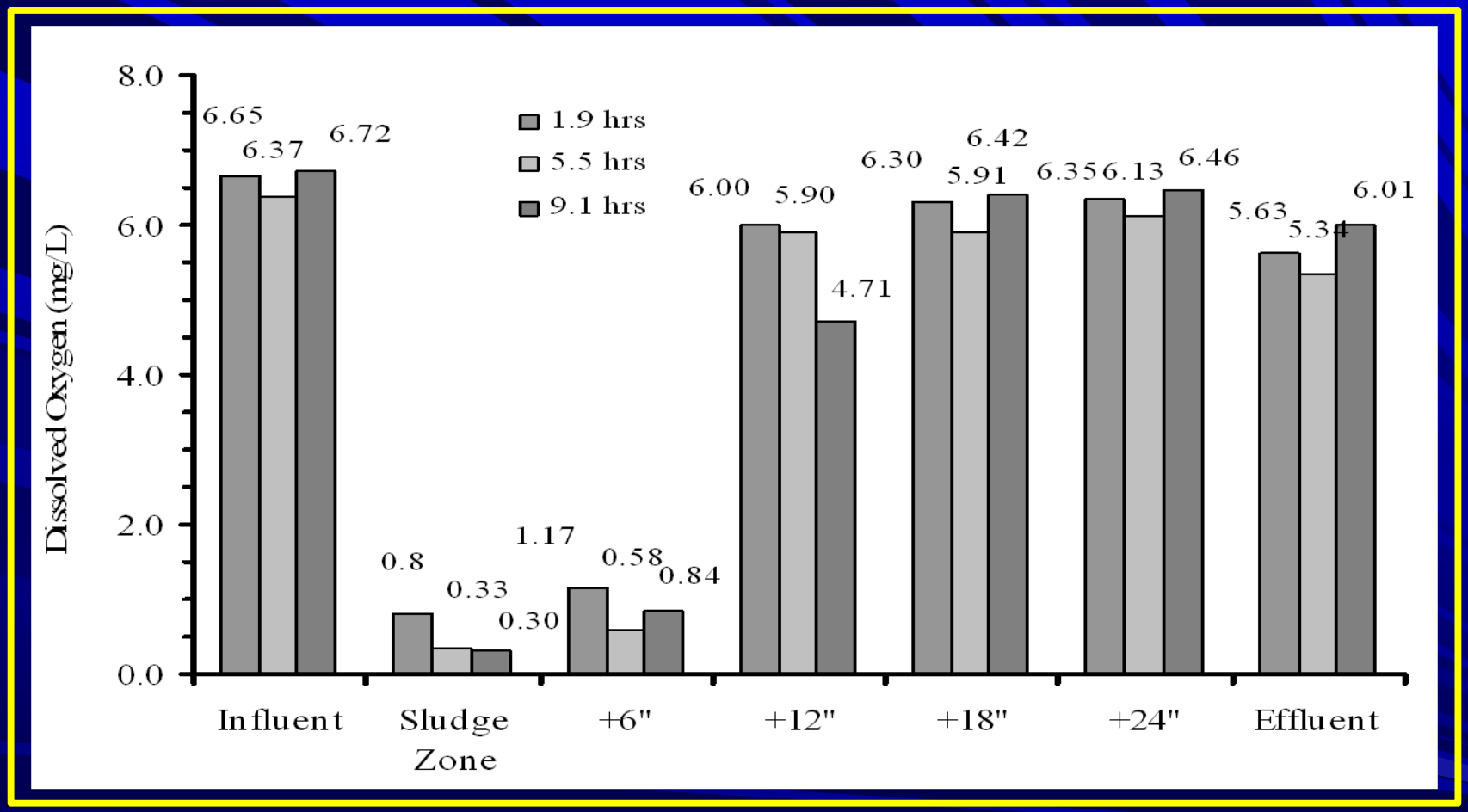
High NO_3 ↓

↑ Low NO_3

Denitrification
$NO_3^- \Rightarrow N_2$
carbon from BOD

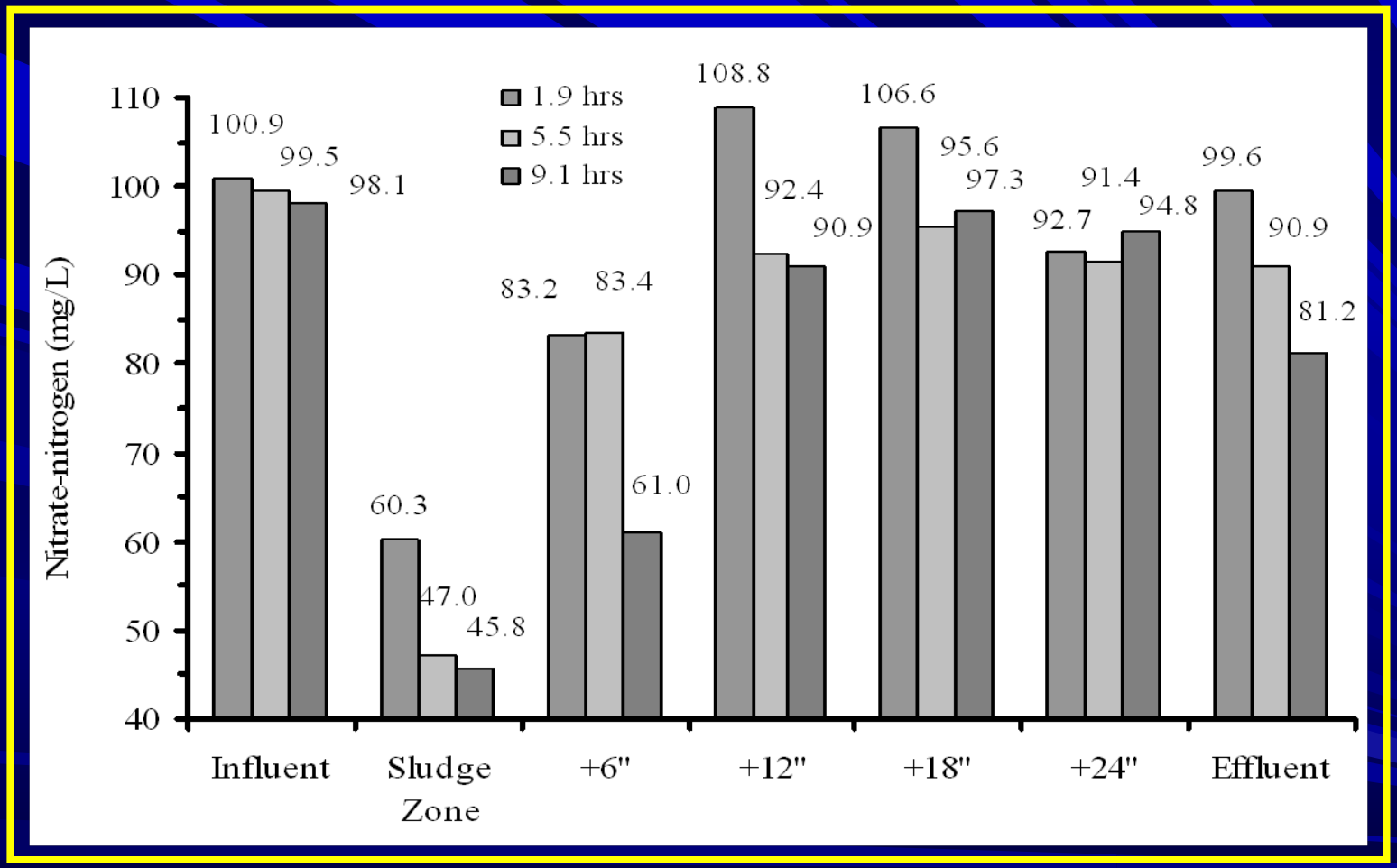
Anoxic Reactor

Anoxic Conditions in the Sludge Zone



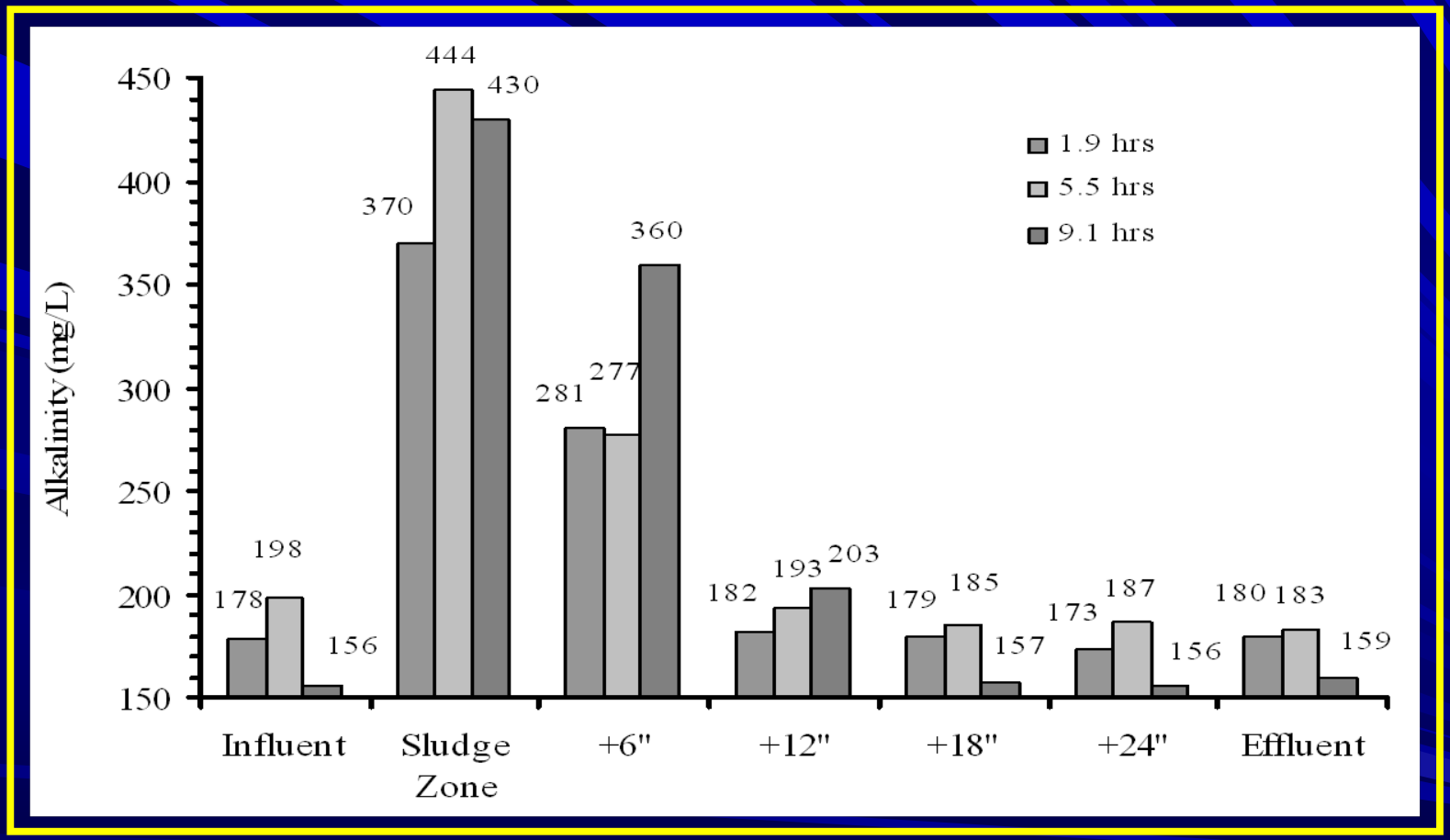
Dissolved Oxygen concentrations across the drop zone and in sludge zone of the DF-3 PolyGeyser® at backwash intervals of 1.9, 5.5, and 9.1 hrs.

Water Quality across DF-3 PolyGeyser®



Nitrate-nitrogen concentrations across the drop zone and in sludge zone of the DF-3 PolyGeyser® at backwash intervals of 1.9, 5.5, and 9.1 hrs.

Water Quality across DF-3 PolyGeyser®



Alkalinity concentrations across the drop zone and in sludge zone of the DF-3 PolyGeyser® at backwash intervals of 1.9, 5.5, and 9.1 hrs

USDA Phase I SBIR

Passive Self-Regulating Denitrification Technology for Aquaculture

Phase I Technical Objectives

- Characterize the volumetric denitrification capacity of floating PHA pellets in AST's PolyGeyser® configuration
- Determine the effect of hydraulic loading rates on denitrification performance
- Conduct basic reactor modeling to project PolyGeyser® denitrification performances for a variety of applications

PolyGeyser® Bead Filter

Anoxic Reactor

NO_3-N

VSS

Denitrification

$NO_3^- \Rightarrow N_2$

carbon from PHA's

Low BOD

High TAN

Low NO_3-N

Polyhydroxyalkanotes (PHAs)

Family of bioplastic polymers, produced from sugar fermentation

- Low Maintenance
- Cost effective
- Carbon source
- Substrate for Bacteria

Denitrification – PHA Stoichiometry

$$NO_3^- + 0.39\ C_4H_6O_2 \longrightarrow 0.088\ C_5H_7O_2N + 0.456\ N_2$$
$$+ HCO_3^- + 0.121\ CO_2 + 0.363\ H_2O$$

Polyhydroxyalkanotes (PHAs)

- excessive biofloc formation at high Nitrate-nitrogen loading & high BOD

Construction of Lab-Scale Experimental PolyGeyser®

Construction of Small-Scale Experimental BioReactors

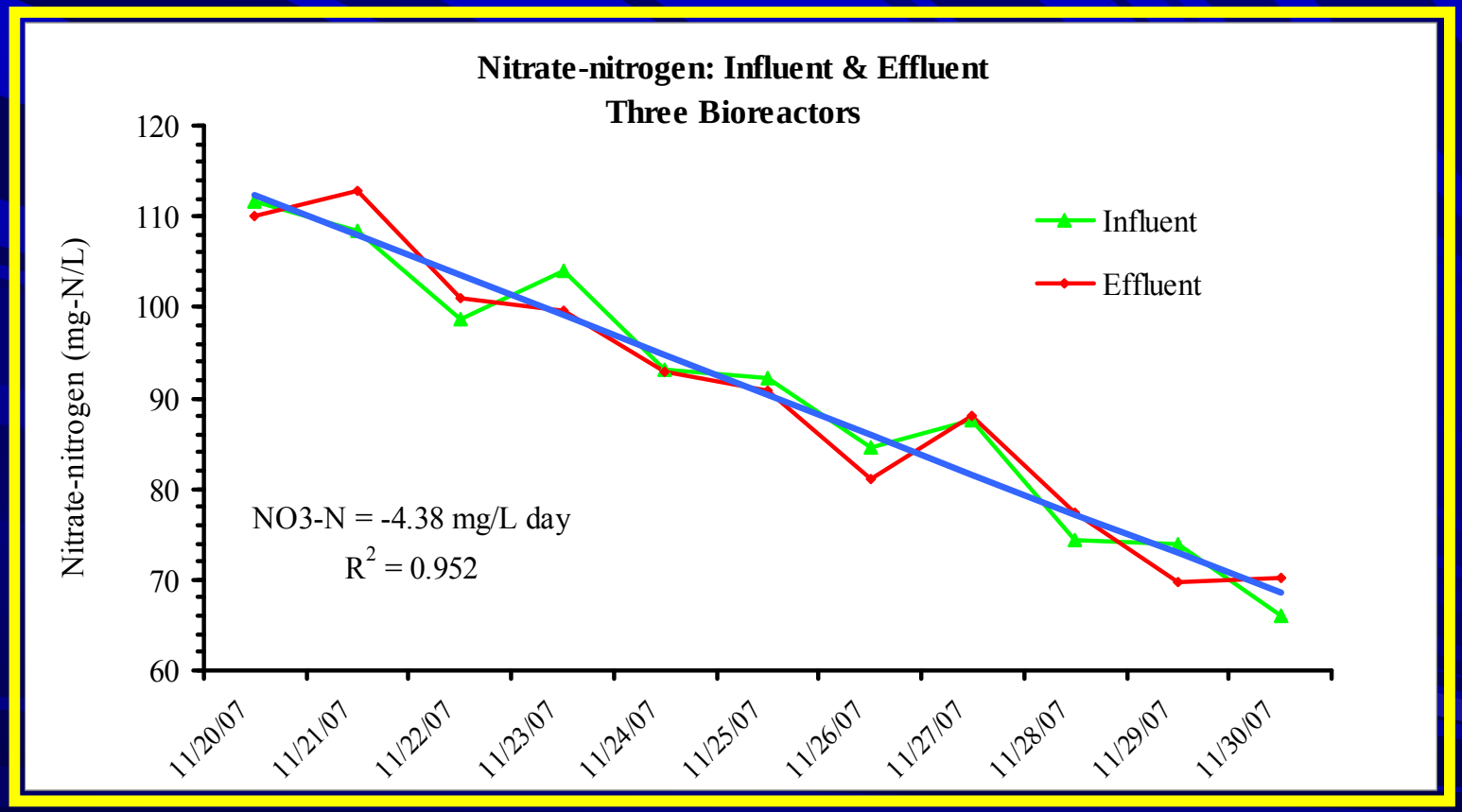
Water Quality Sampling

Parameter	Method / Range
DO / Temperature	YSI Model 58 Dissolved Oxygen Meter
Salinity / Conductivity	YSI Model 33 S-C-T Meter
Nitrogen – Ammonia	Hach Method 8038 Nessler Method 0 – 2.50 mg/L NH_3-N
Nitrogen –Nitrite	Hach Method 8507 Diazotization Method 0 – 0.300 mg/L NO_2^- -N
Nitrogen -Nitrate	Hach Method 8039 Cadmium Reduction Method 0.0 – 10.0 mg/L NO_3^- - N
Alkalinity	Standard Methods 2320B as $CaCO_3$

PolyGeyser® - Backwash

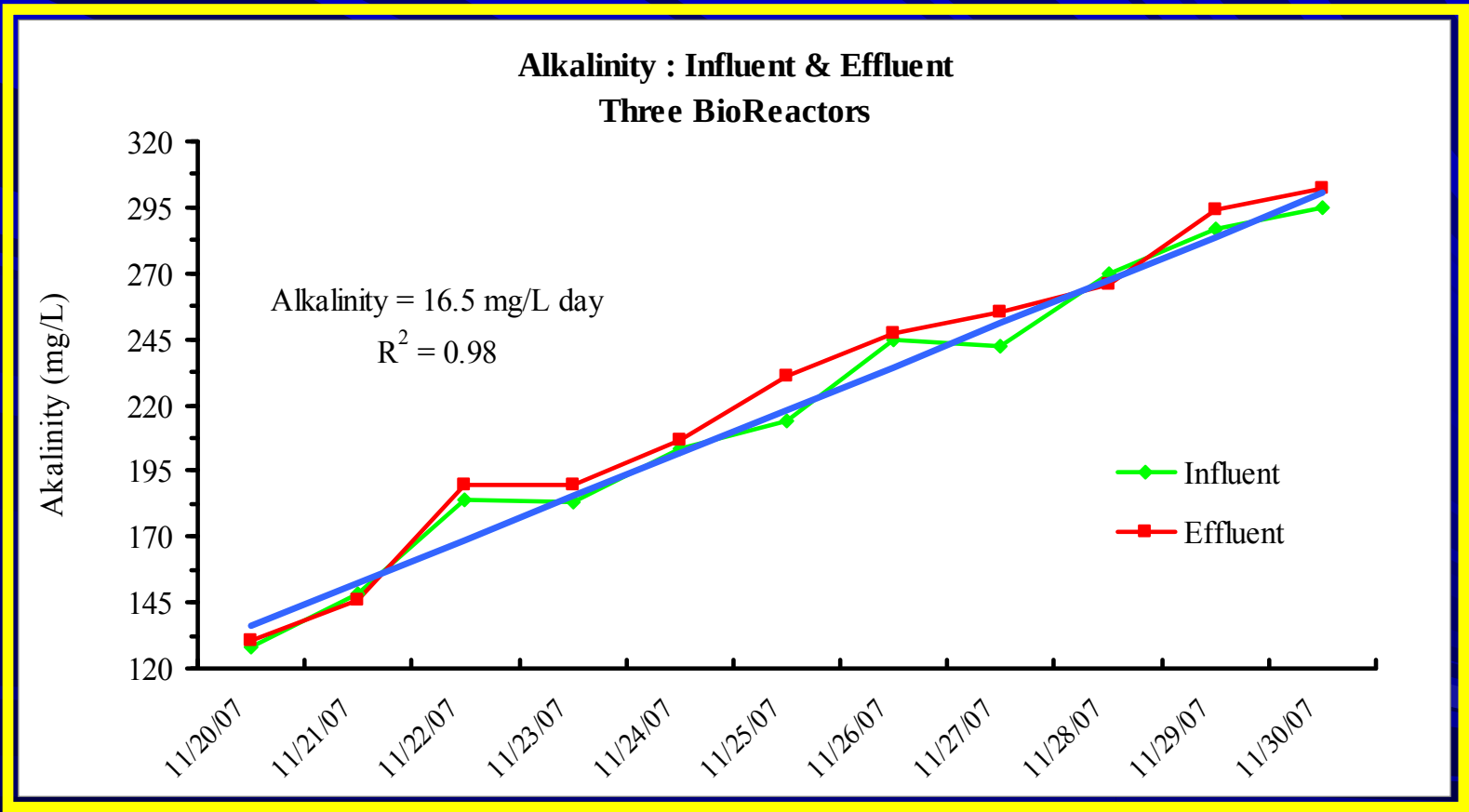
Solids Removal

Acclimation of Experimental Denitrification Units at High Nitrate-nitrogen



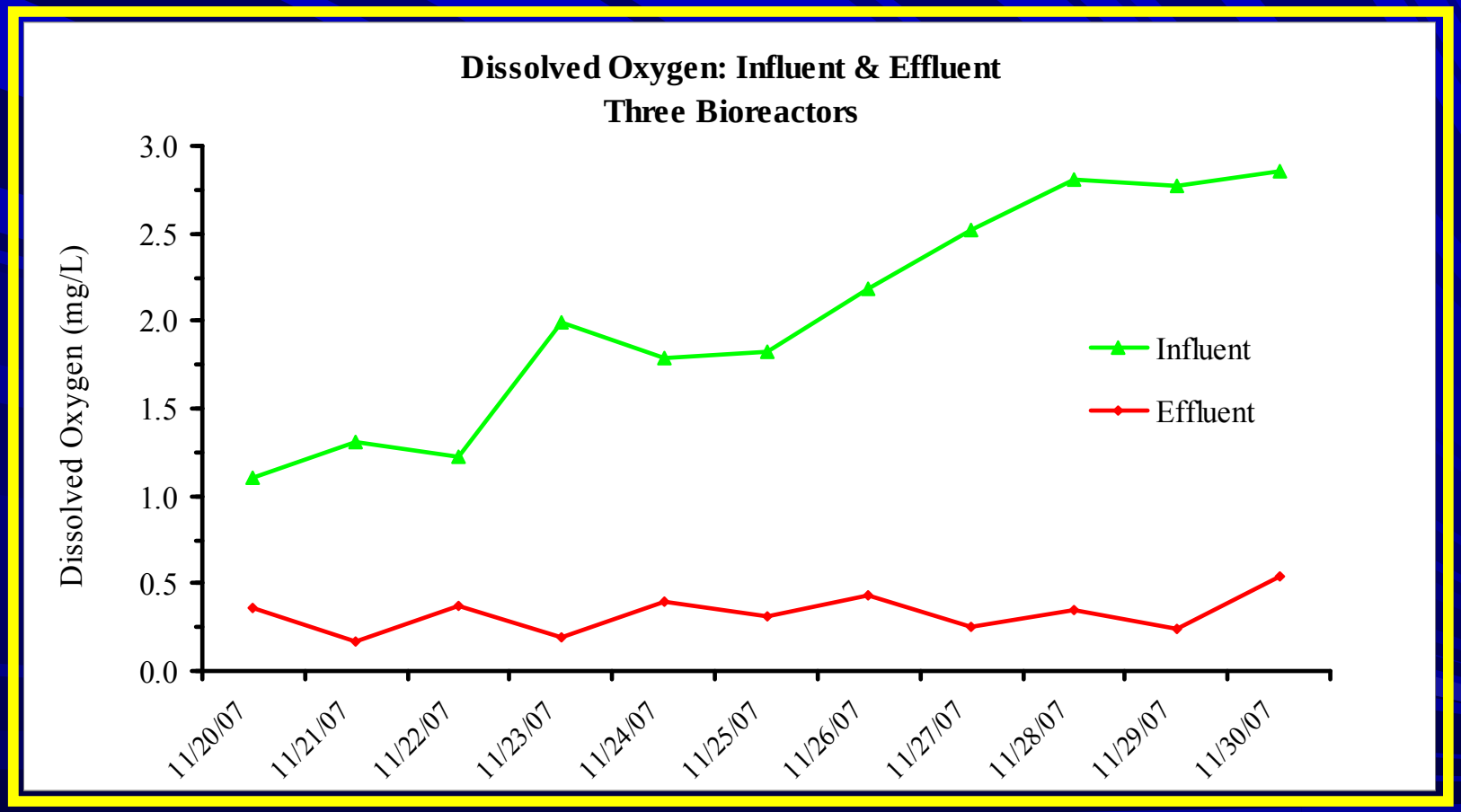
150 mL/min Flow Rate

Acclimation of Experimental Denitrification Units at High Nitrate-nitrogen



Alkalinity / NO_3-N = 3.77

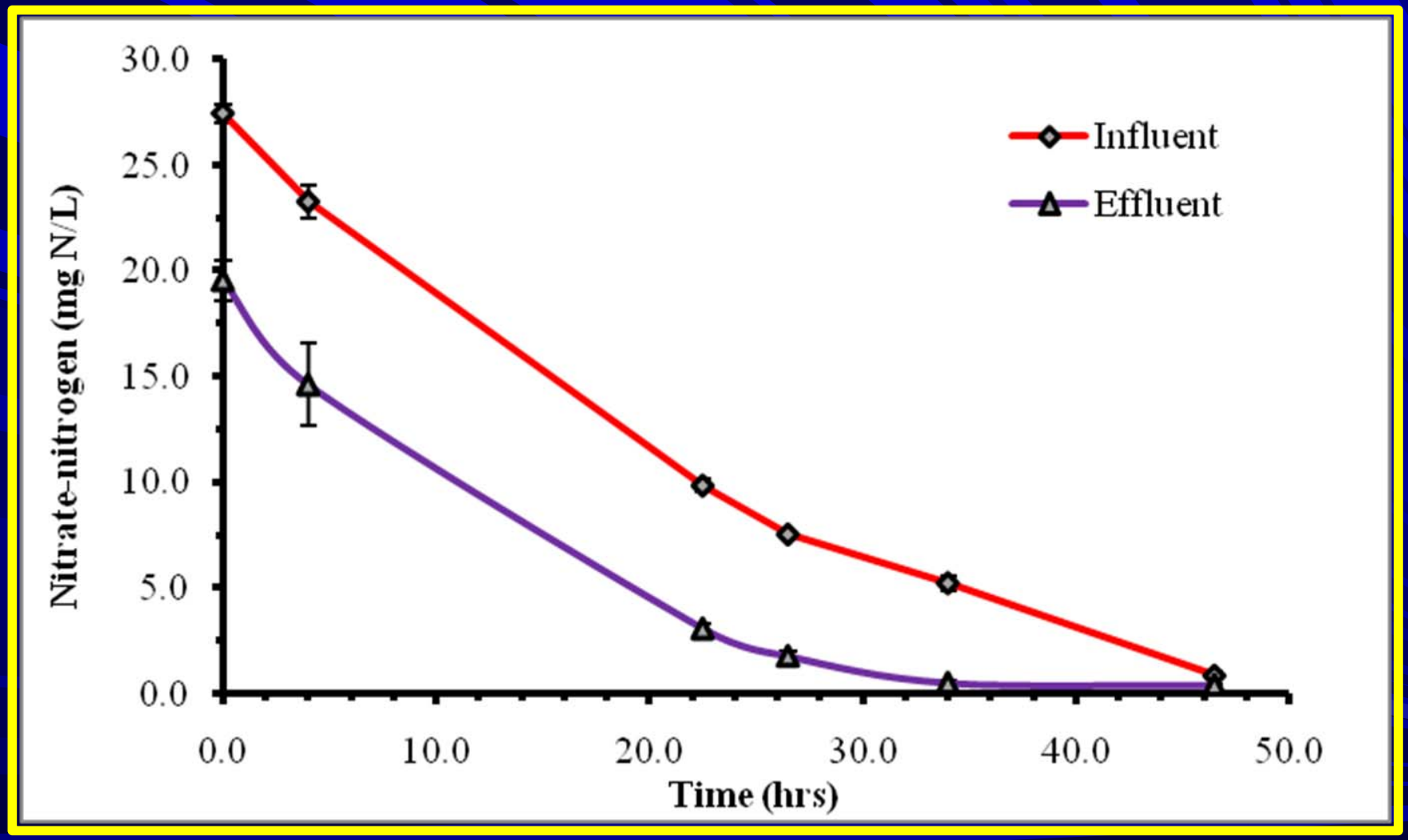
Acclimation of Experimental Denitrification Units at High Nitrate-nitrogen



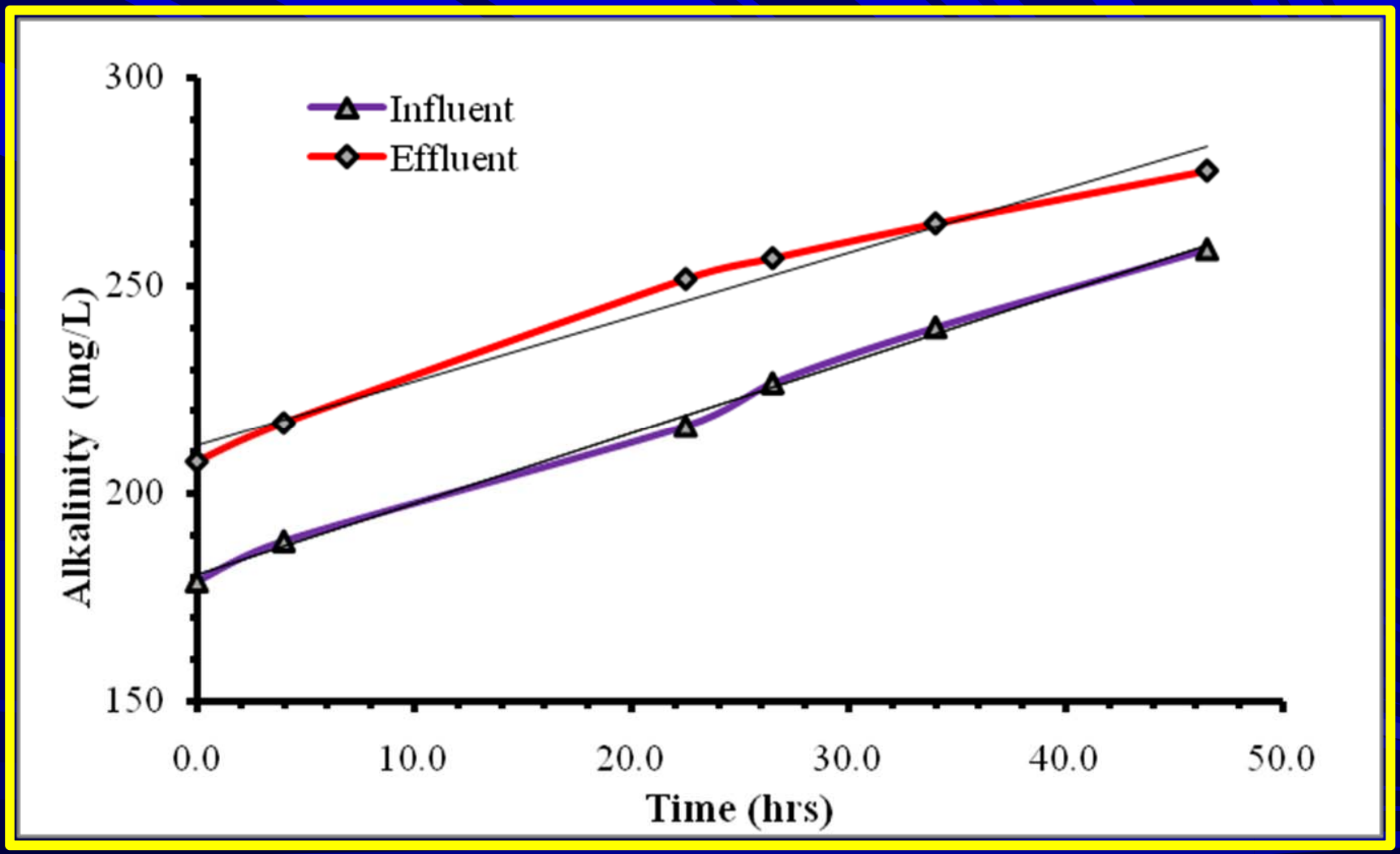
Marine Lab-Scale BioReactors

- Salinity – 10 to 32 ppt
- Low BOD
- Low TSS
- Nitrate – 50 to 250 mg/L-N

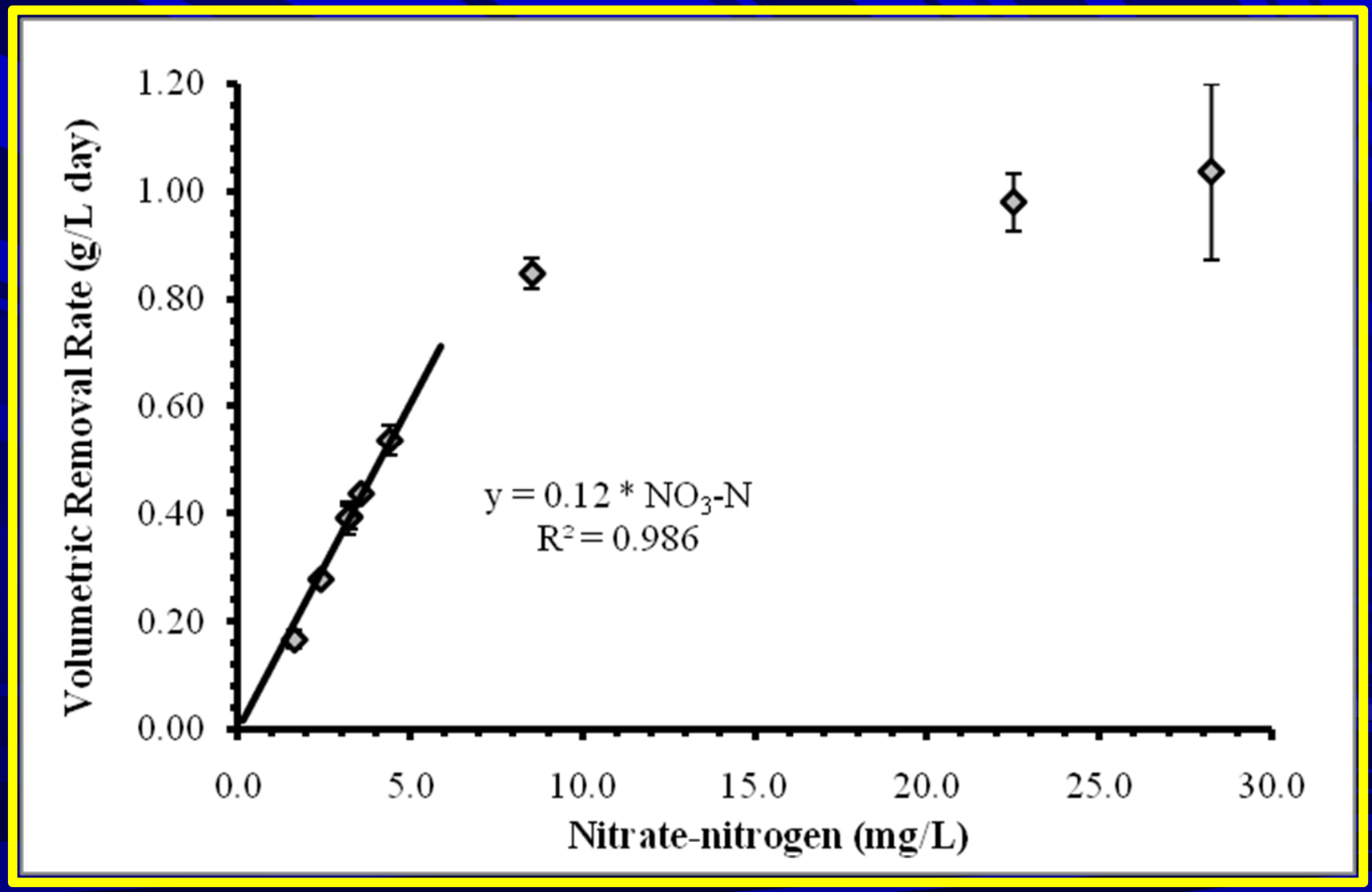
Nitrate-nitrogen Across BioReactors



Alkalinity Across BioReactors



Volumetric Nitrification Removal Rate



Conclusions

- Three lab-scale denitrification BioReactor were designed, constructed and operated
- Three lab-scale PolyGeyser® denitrification unit was designed, constructed and are operating
- “proof – of-concept”

Questions?

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