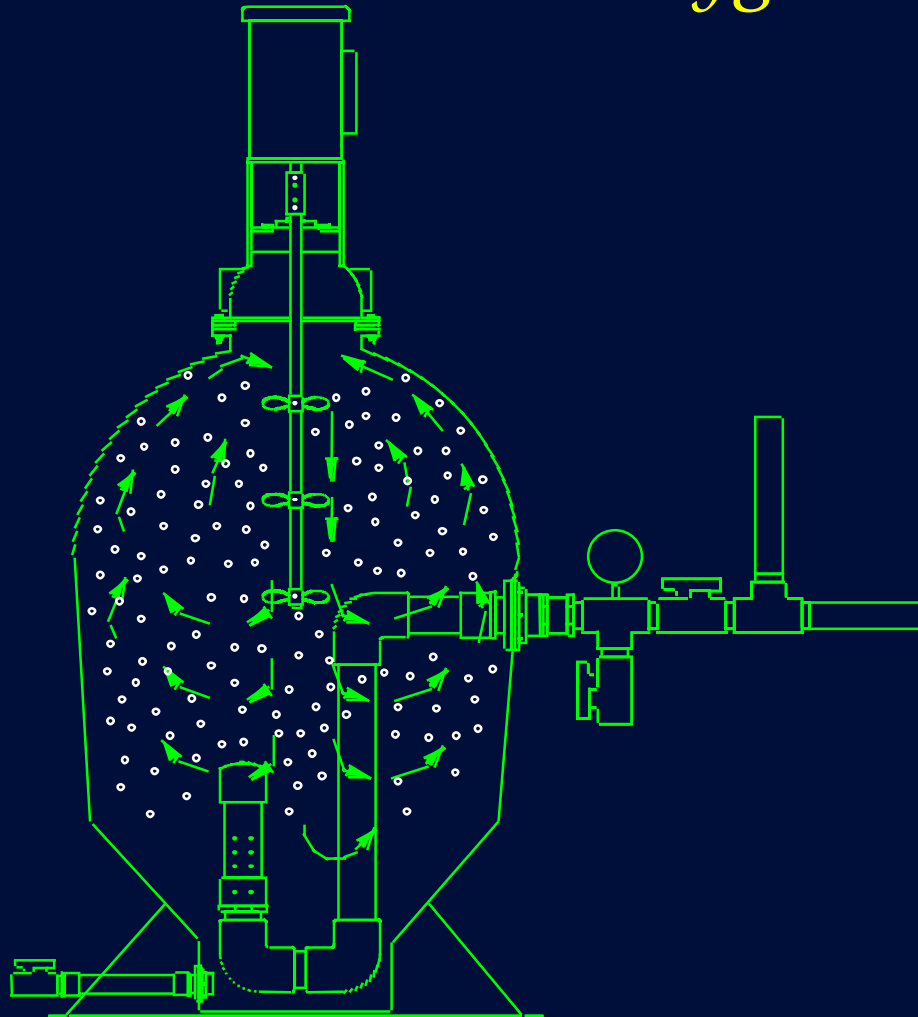


# *Modeling the Effects of Solids Accumulation on Oxygen Demand & Transport in Floating-Bead Filters*



**William J. Golz, PhD**

**Kelly A. Rusch, PhD**

**Ronald F. Malone, PhD**

Louisiana State University

Research Funded by  
Louisiana Board of Regents &  
Louisiana Sea Grant College Program

# Aquaculture in Closed Systems

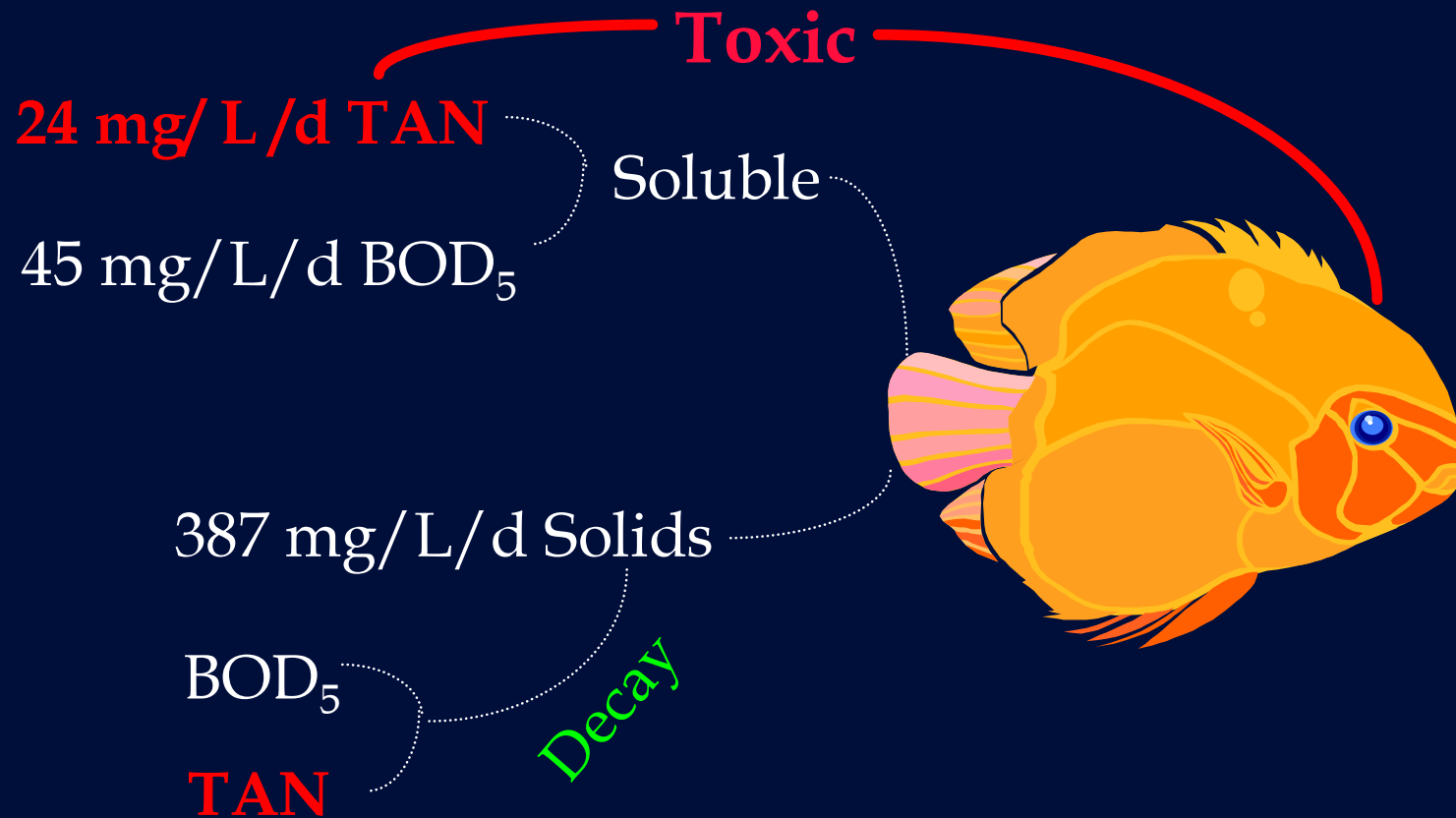
- Reliable environmental control
  - ✕ Indoors
  - ✕ Low water exchange rate
- Effective for culturing highly-valued products
  - ✕ Endangered Kemp's Ridley Sea Turtle
  - ✕ Squid for biomedical research
  - ✕ Ornamental Koi
- Increased production of commodity products
  - ✕ Closed-system: \$ 1 - 1.50 per pound
  - ✕ Pond culture: \$ 0.50 - 0.75 per pound



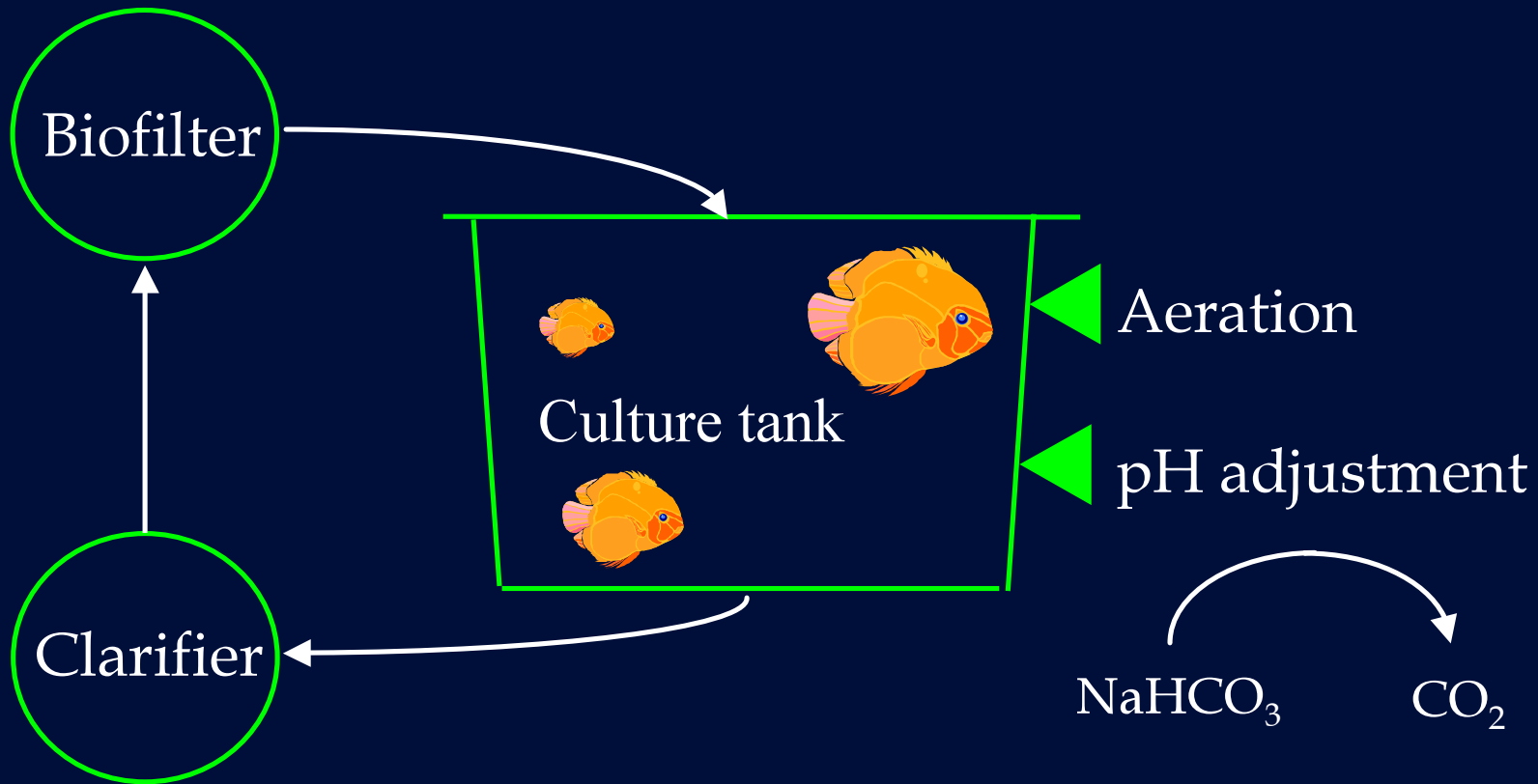
# Two Approaches to Cost Reduction

- Increase production
  - ✕ System intensification
- Lower system costs
  - ✕ Combining treatment components
  - ✕ Optimizing component performance

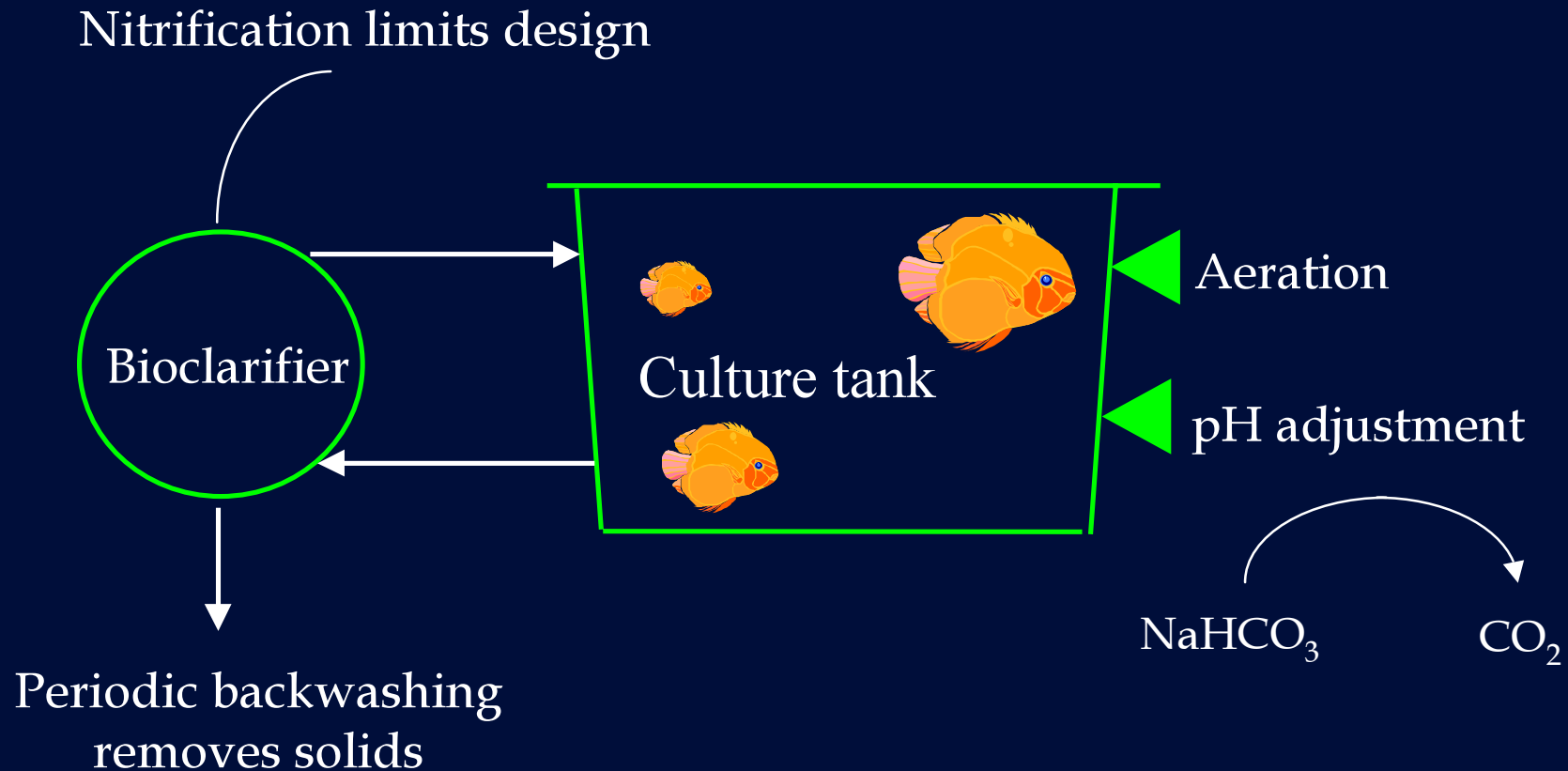
# Waste Excretions at a Typical Stocking Density and Feed Rate



# Typical Recirculating Aquaculture System (RAS)



# FBFs Combine Biofiltration & Clarification





# Objectives

- Define the major factors limiting nitrification
  - ✗ Effects of solids decay
  - ✗ Effect of washing energy on biomass concentration
- Define strategies for improving filter performance
  - ✗ Develop a rational basis for filter management
  - ✗ Recommend design improvements



# Model

- System of eight differential equations
  - ✗ First-order solids decay
  - ✗ Monod expressions for nitrification
  - ✗  $BOD_5$  & DO have limiting effects on nitrification
- Assumptions
  - ✗ All solids are captured by the filter
  - ✗ The FBF and culture tank behave like CFSTRs
  - ✗ Oxygen-transfer resistance is the only non-constant limitation
- Calibrated against two heavily-loaded filters
  - ✗ BBF - Gentle wash
  - ✗ PBF - Aggressive wash



# Solids Capture Inhibits Nitrification in Two Ways

Decay

Particulate Occlusion

Internal load

Reduced flow

More biomass

Increased respiration

Decreased O<sub>2</sub> delivery



Depressed Nitrification

# Solids Consist of Primary Excretions & Heterotrophic Biomass

$$\frac{d}{dt} P_s = \frac{F_{LR}}{2.2} V_M E_S - M_S S_V k_S$$

Excretions (points to  $F_{LR}$ )

First - order VS decay (points to  $k_S$ )

Solids amonification (points to  $k_S$ )

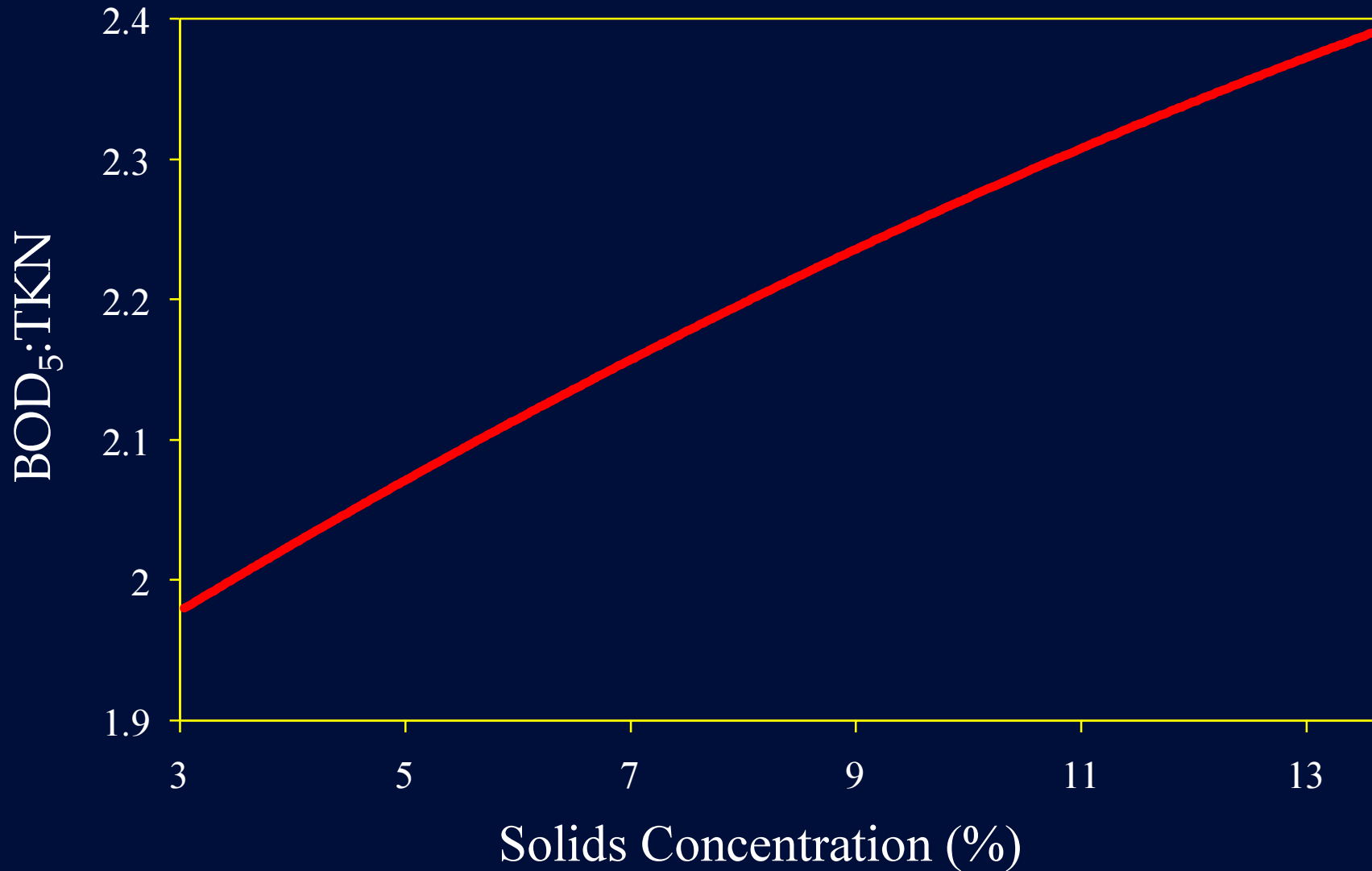
TKN:VS = 0.05

BOD<sub>5</sub>:VS = 0.15

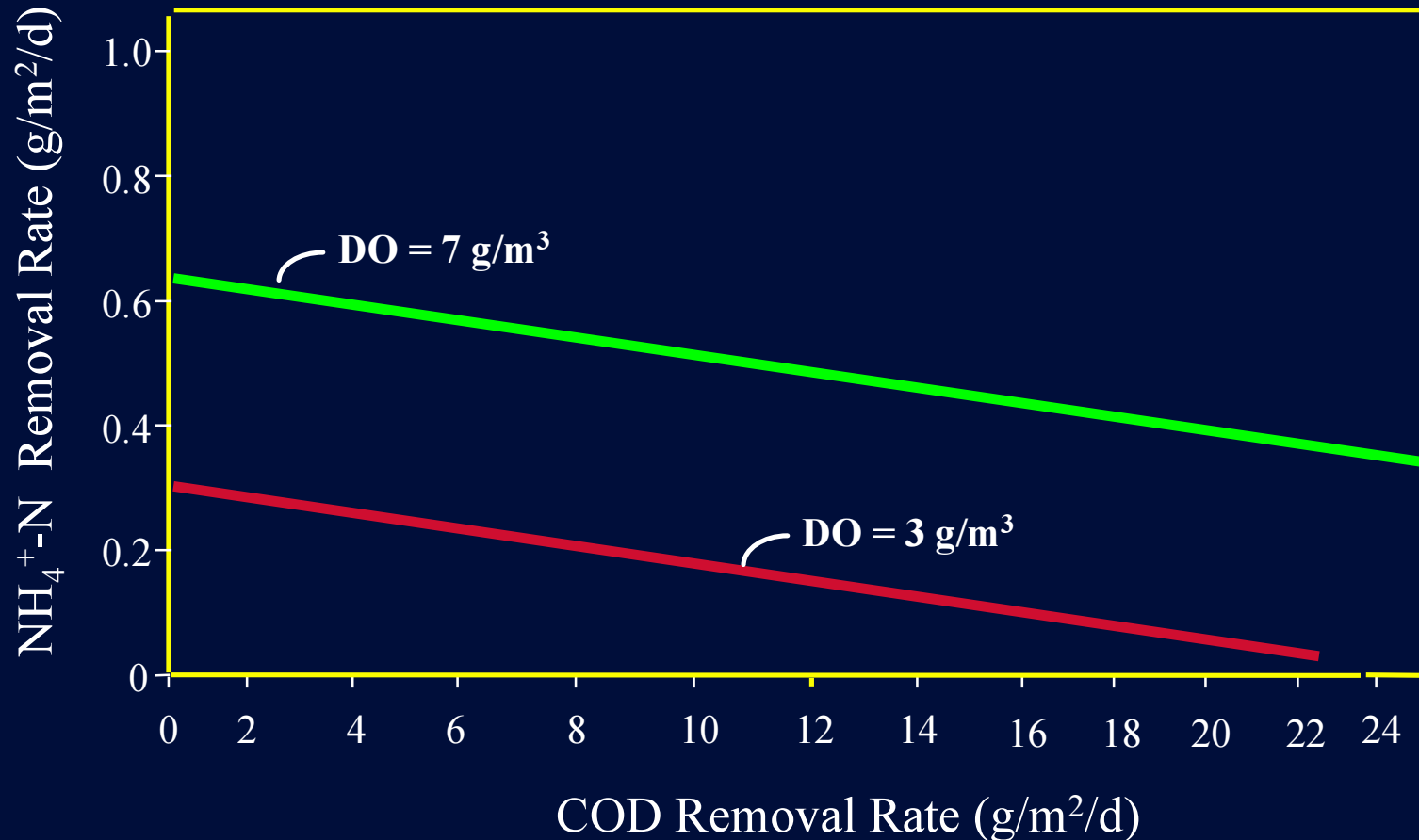
BOD<sub>5</sub> from decay (points to  $k_S$ )

$$\frac{d}{dt} X_H = \frac{\mu_{mh} X_H B_B}{K_{SB} + B_B} - k_d X_H$$

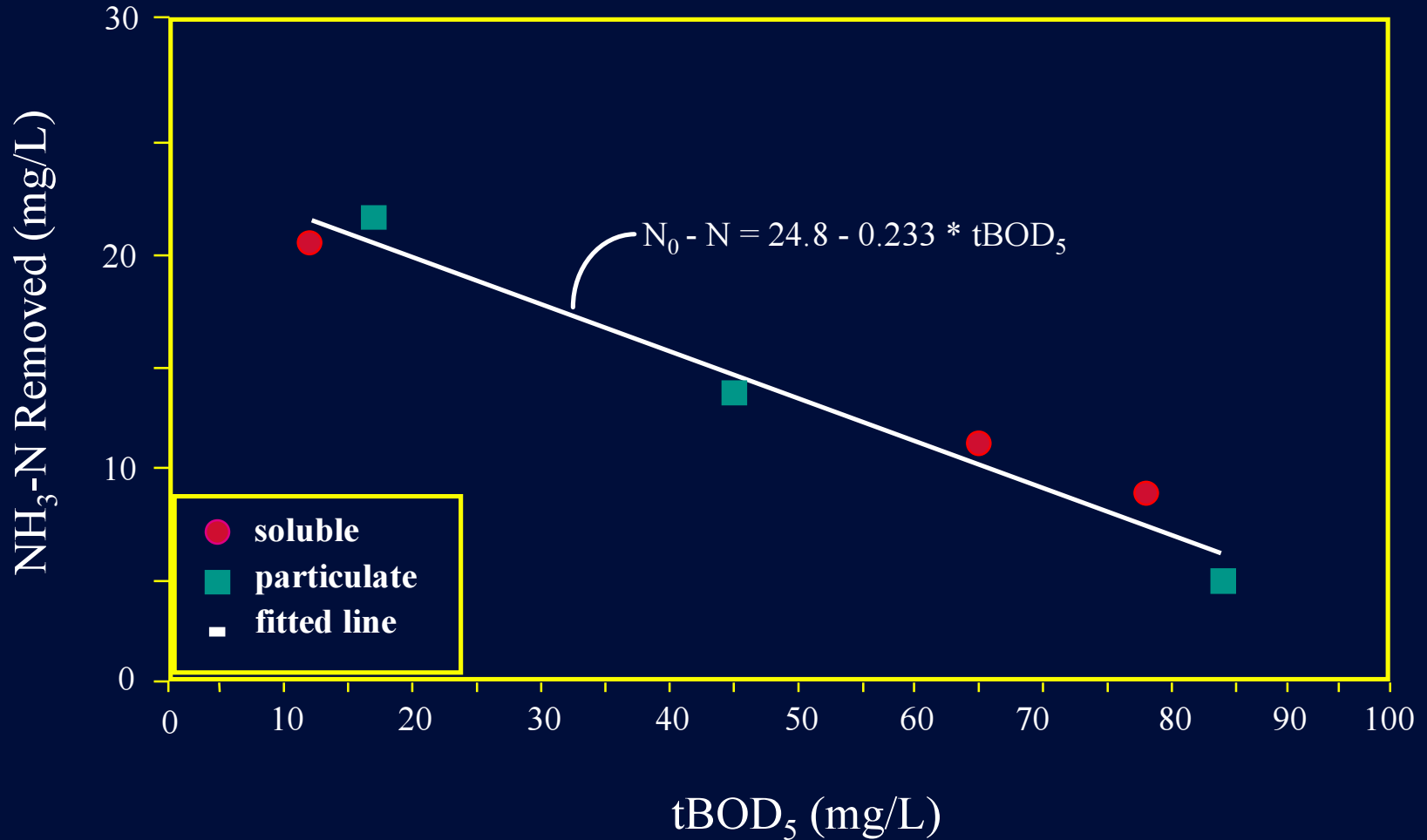
## BOD<sub>5</sub>:TKN Ratio Increases with Solids Concentration



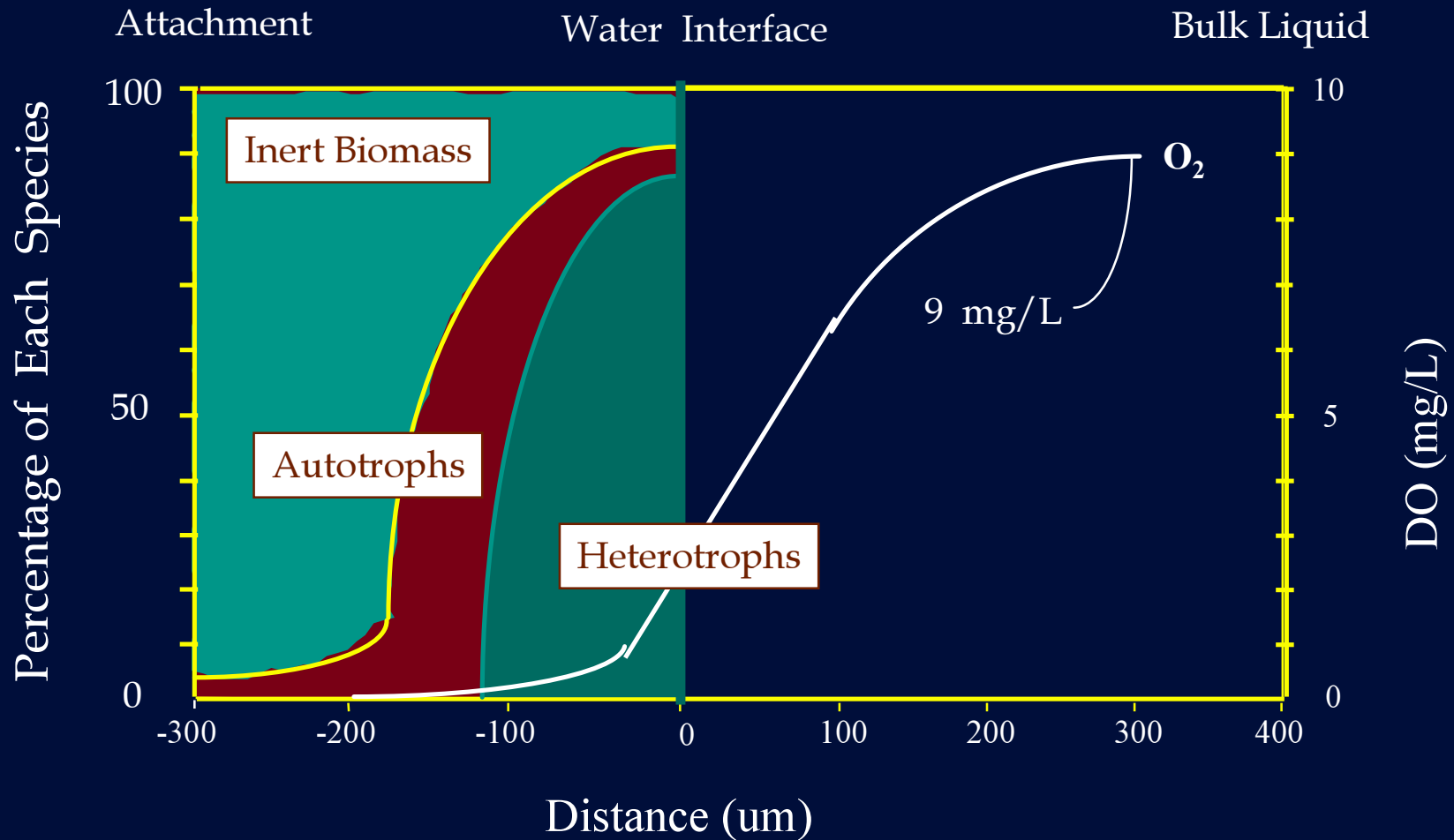
In a trickling filter used in a RAS, nitrification declined when COD was increased or DO was lowered (Bovendeur *et al.* 1990)



# Soluble or particulate BOD<sub>5</sub> identically inhibited NH<sub>3</sub>-N removal (Figueroa & Silverstein 1992)



Heterotrophs can dominate the biofilm surface,  
exhausting most oxygen before it reaches the nitrifiers  
(Rittmann & Manem 1992, Zhang *et al.* 1995)



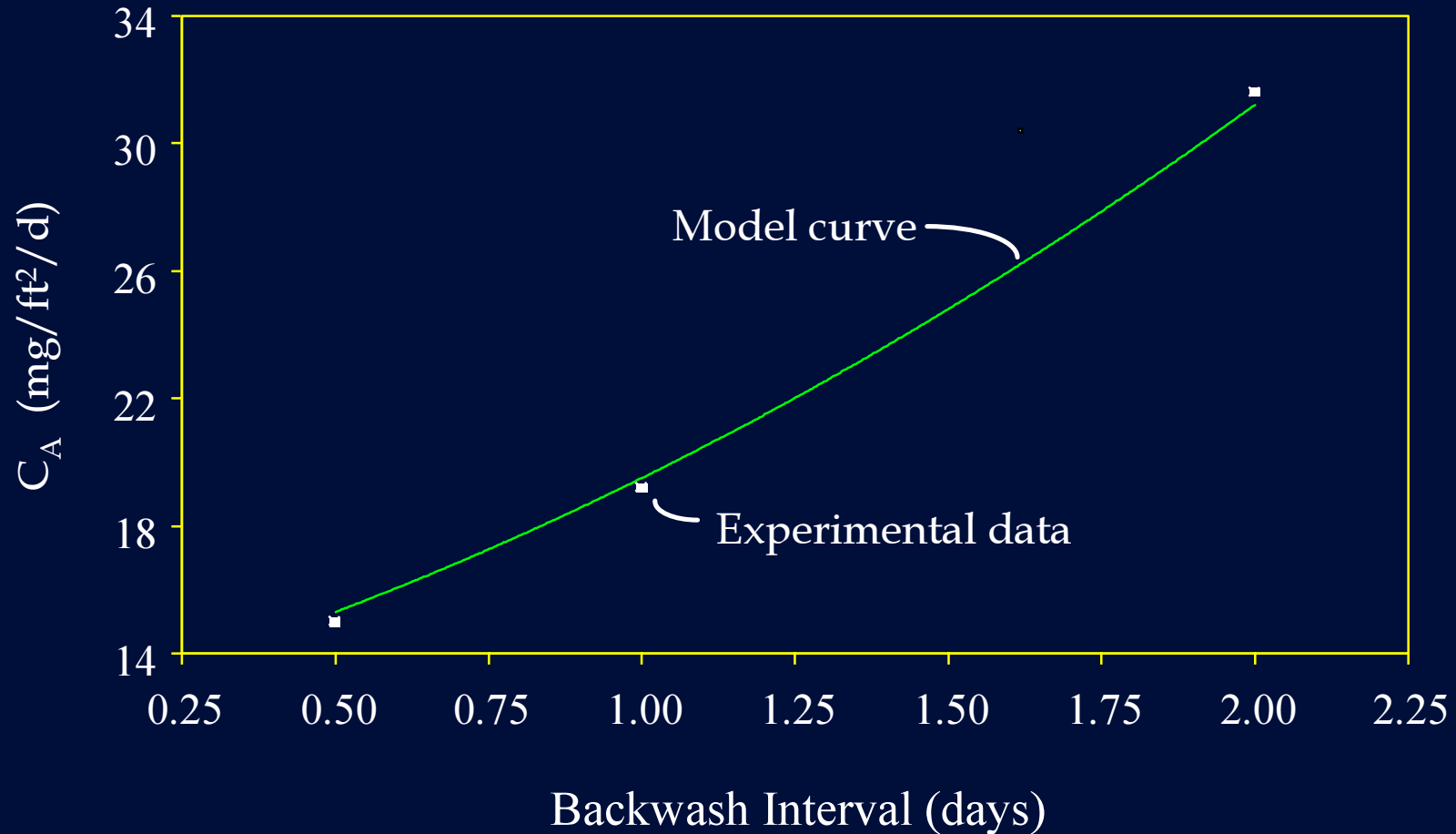
# Biofilter TAN Concentration

$$\frac{d}{dt} A_B = \left[ \underbrace{Q_R 5451 (A_T - A_B) + M_S S_V S_N k_S}_{\text{Mass exchange}} - \underbrace{\left( \frac{\mu_{m n} X_N A_B}{K_{SA} + A_B} \right) \left( \frac{O_B}{K_{SO} + O_B} \right)}_{\text{Oxygen transport resistance}} \right] \left( \frac{1}{V_M n} \right)$$

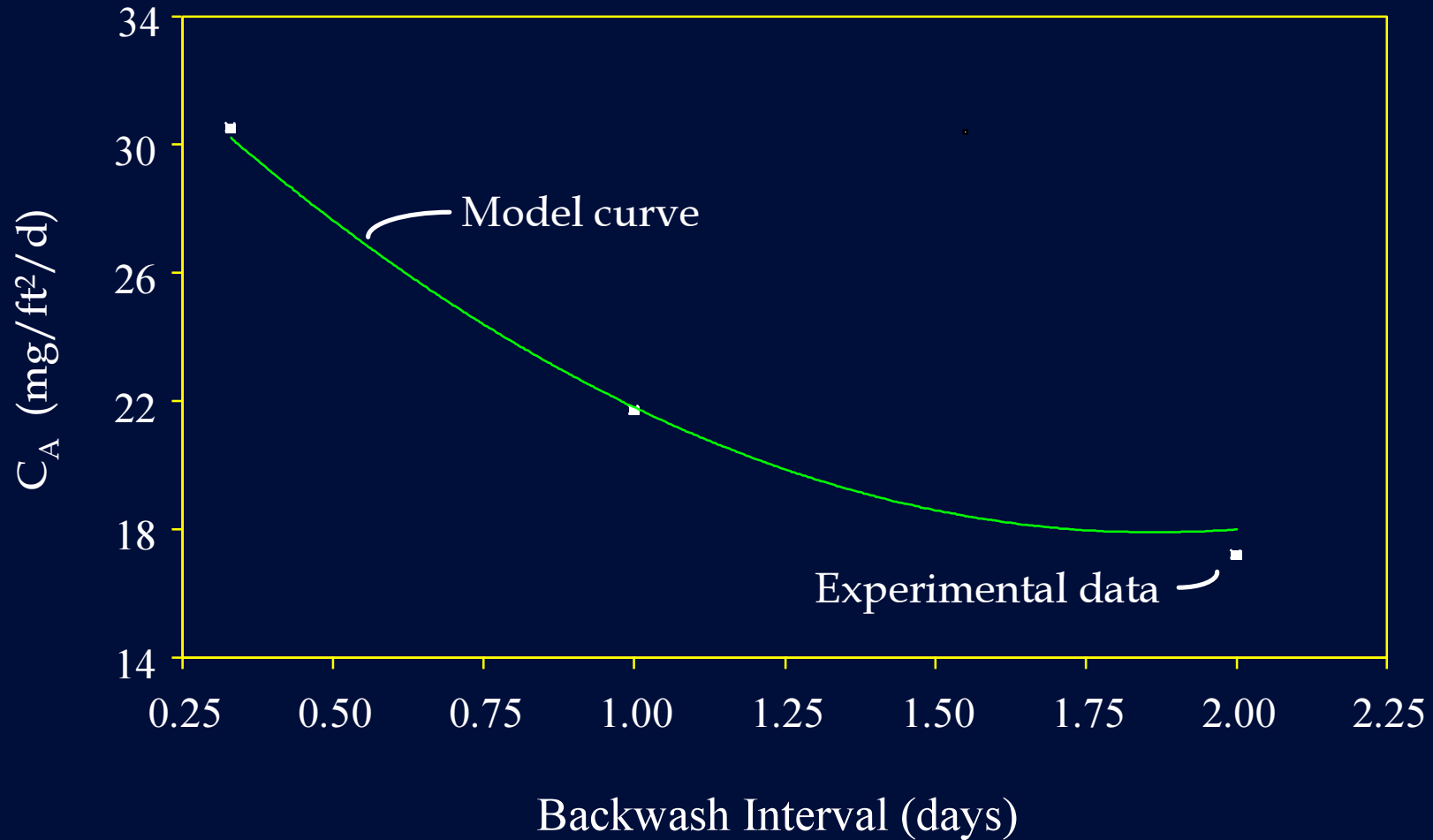
Solids amonification

$$C_A = \frac{Q_R 5451 (A_T - A_B)}{V_M S_A} \quad \text{Apparent Nitrification Rate}$$

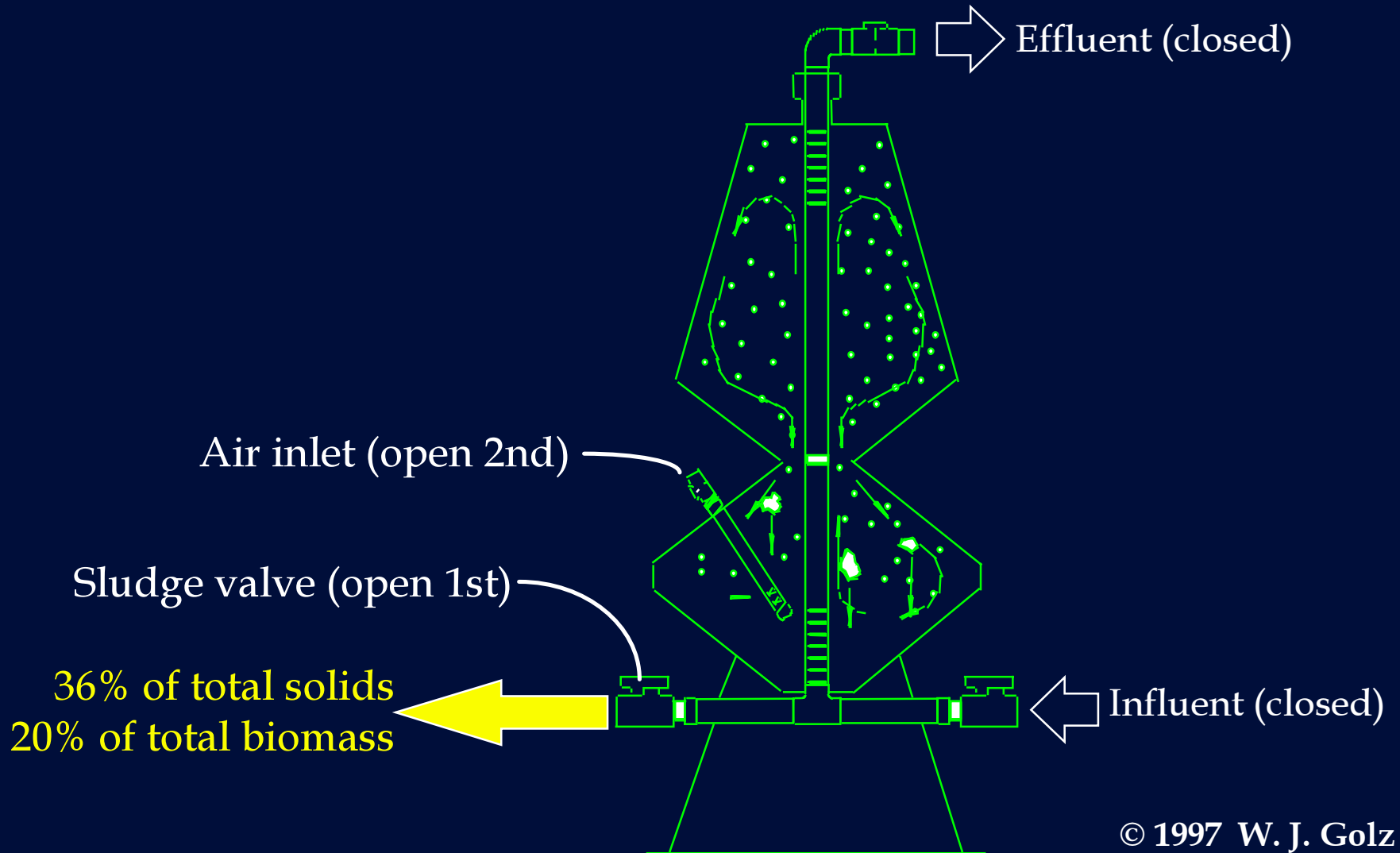
# Calibration Curve for the Aggressively-Washed Filter



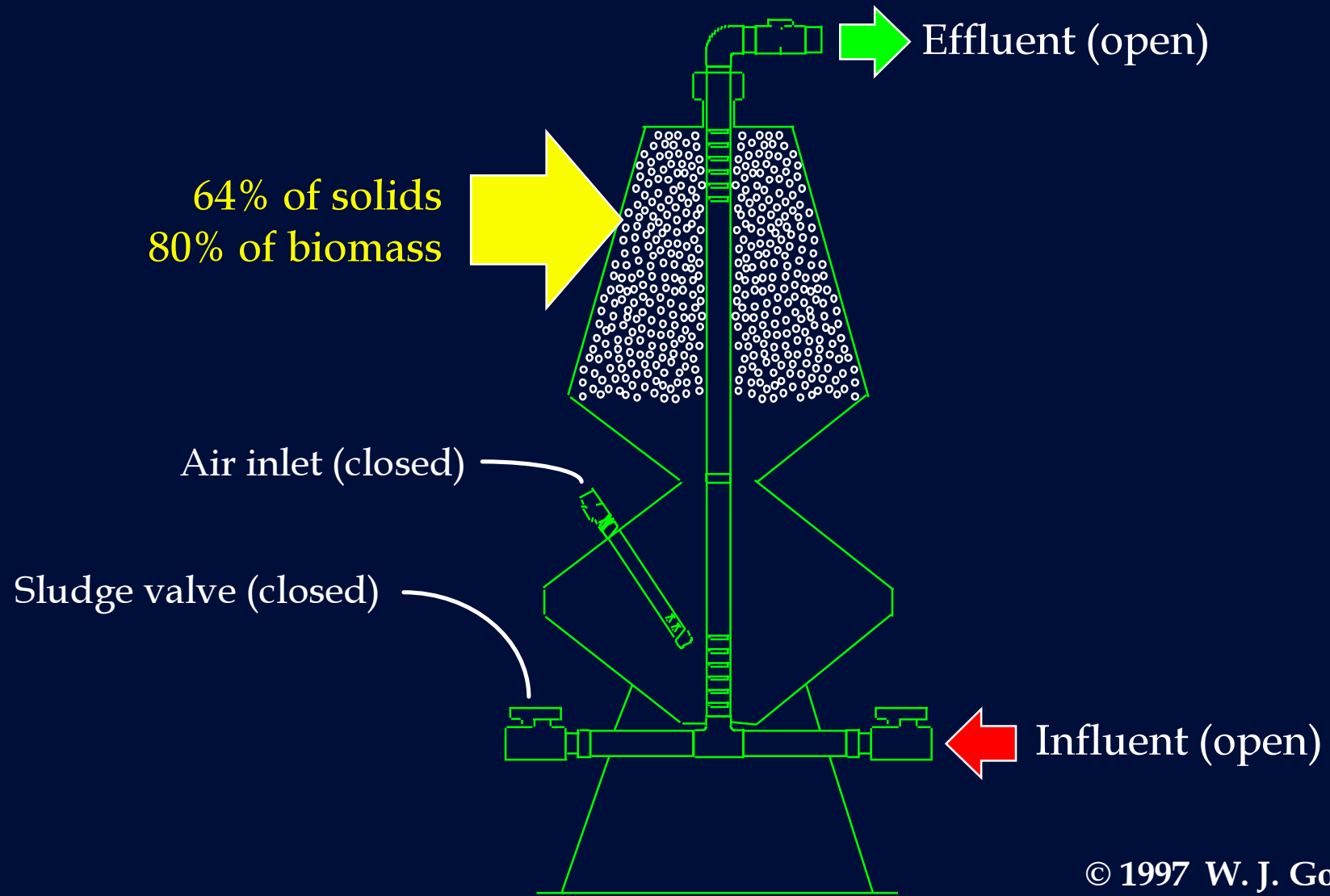
## Calibration Curve for the Gently-Washed Filter



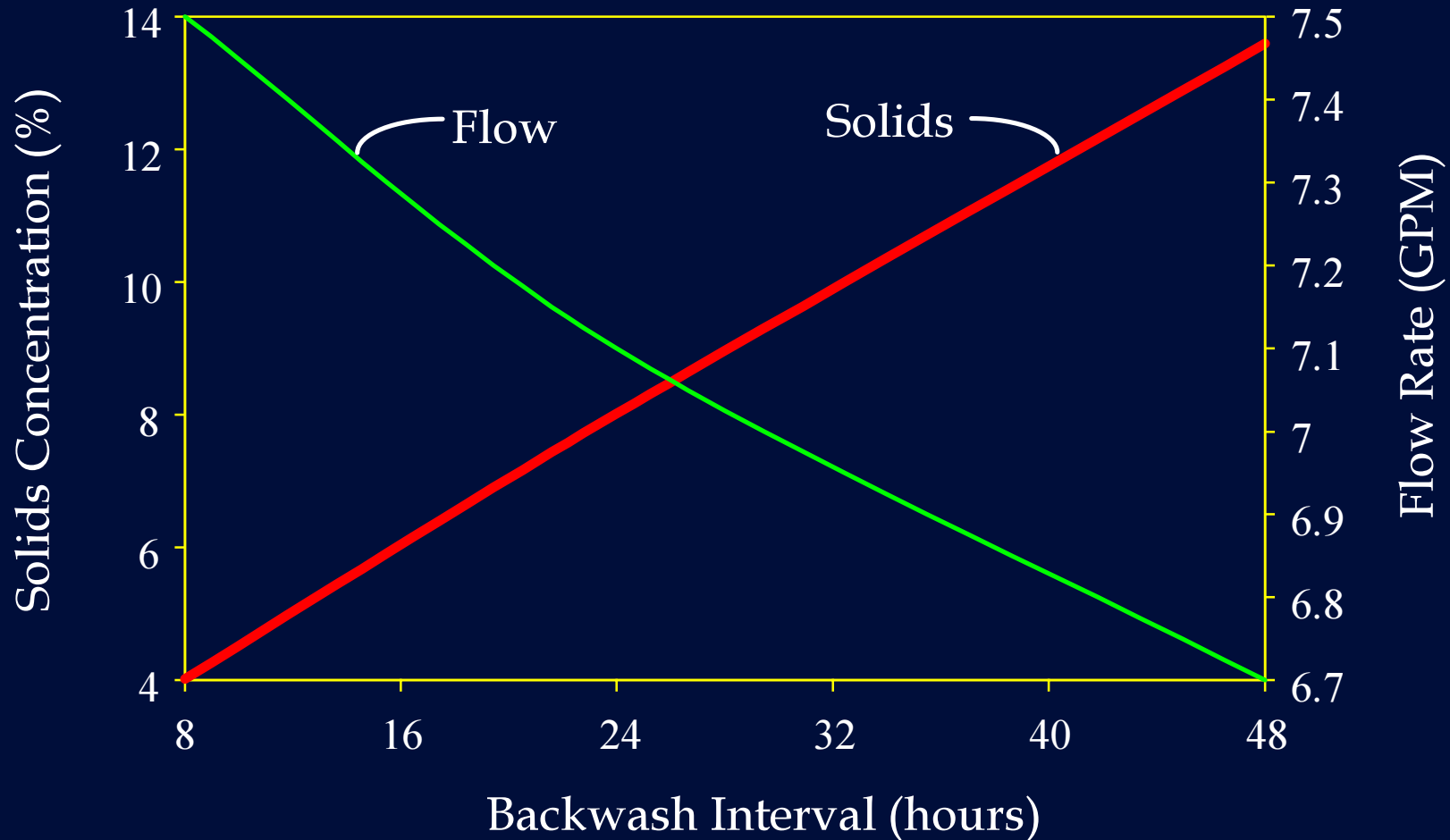
# BBF-Gentle Pneumatic Wash



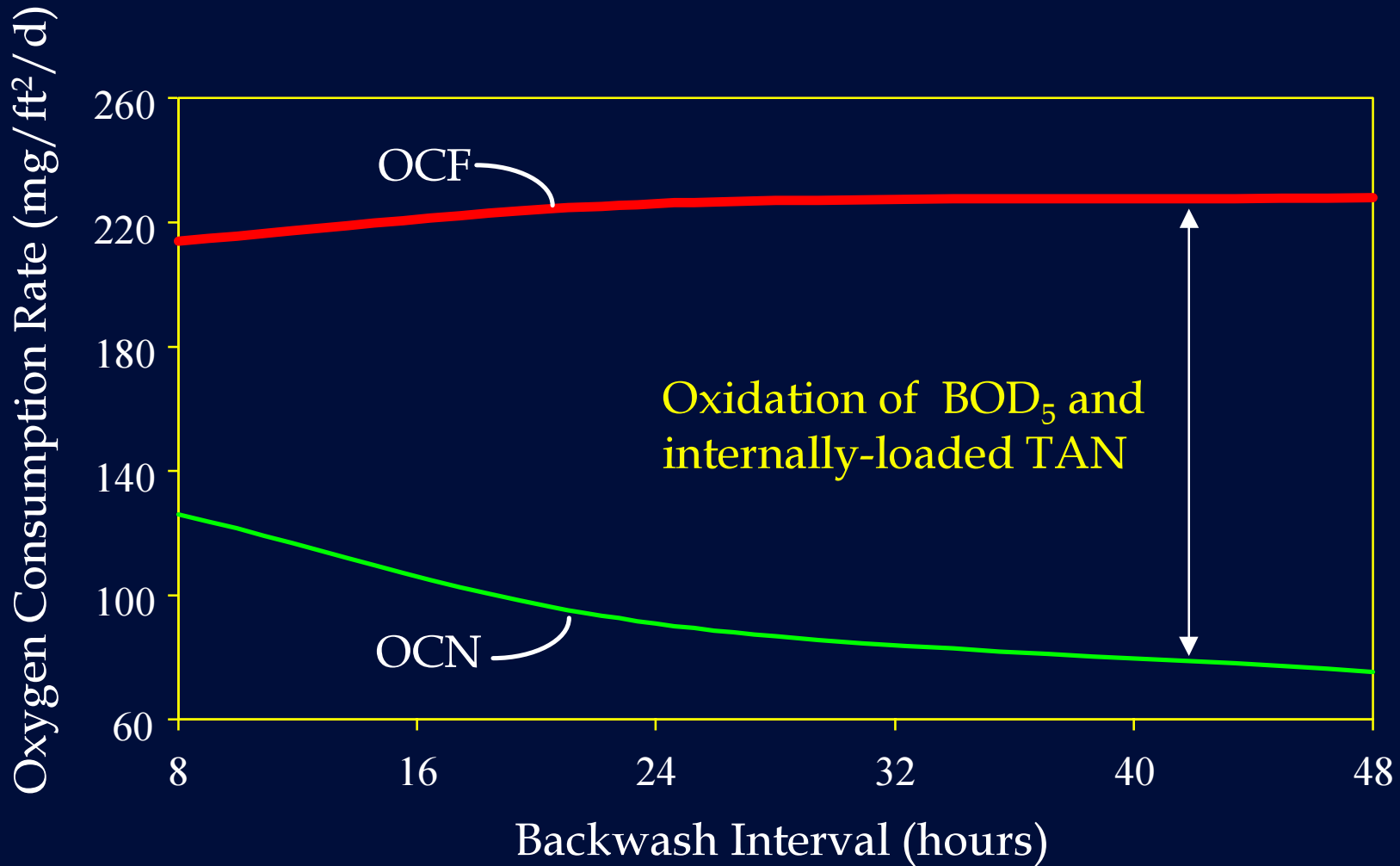
# BBF Filtration Mode



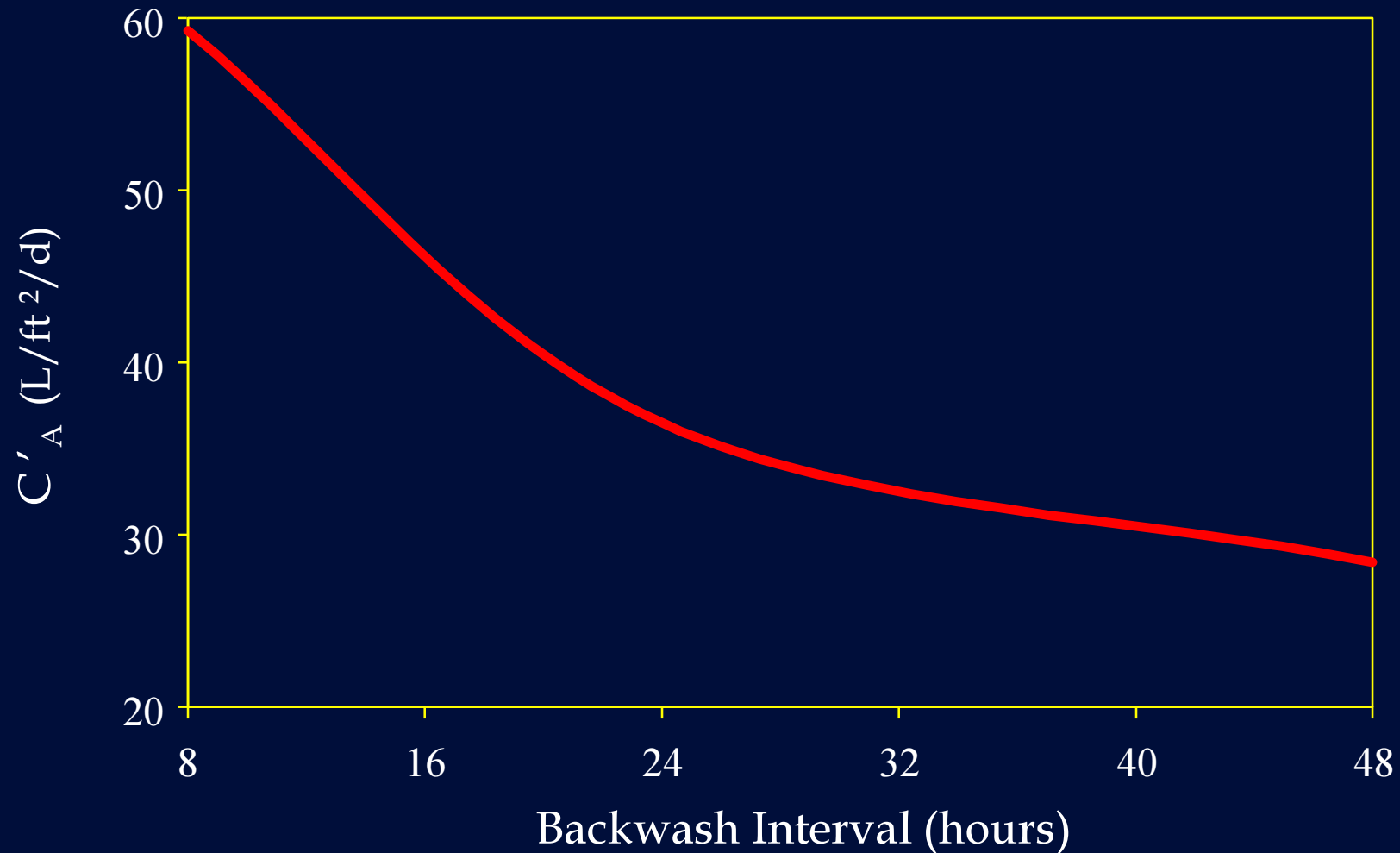
As internal load increases, flow declines



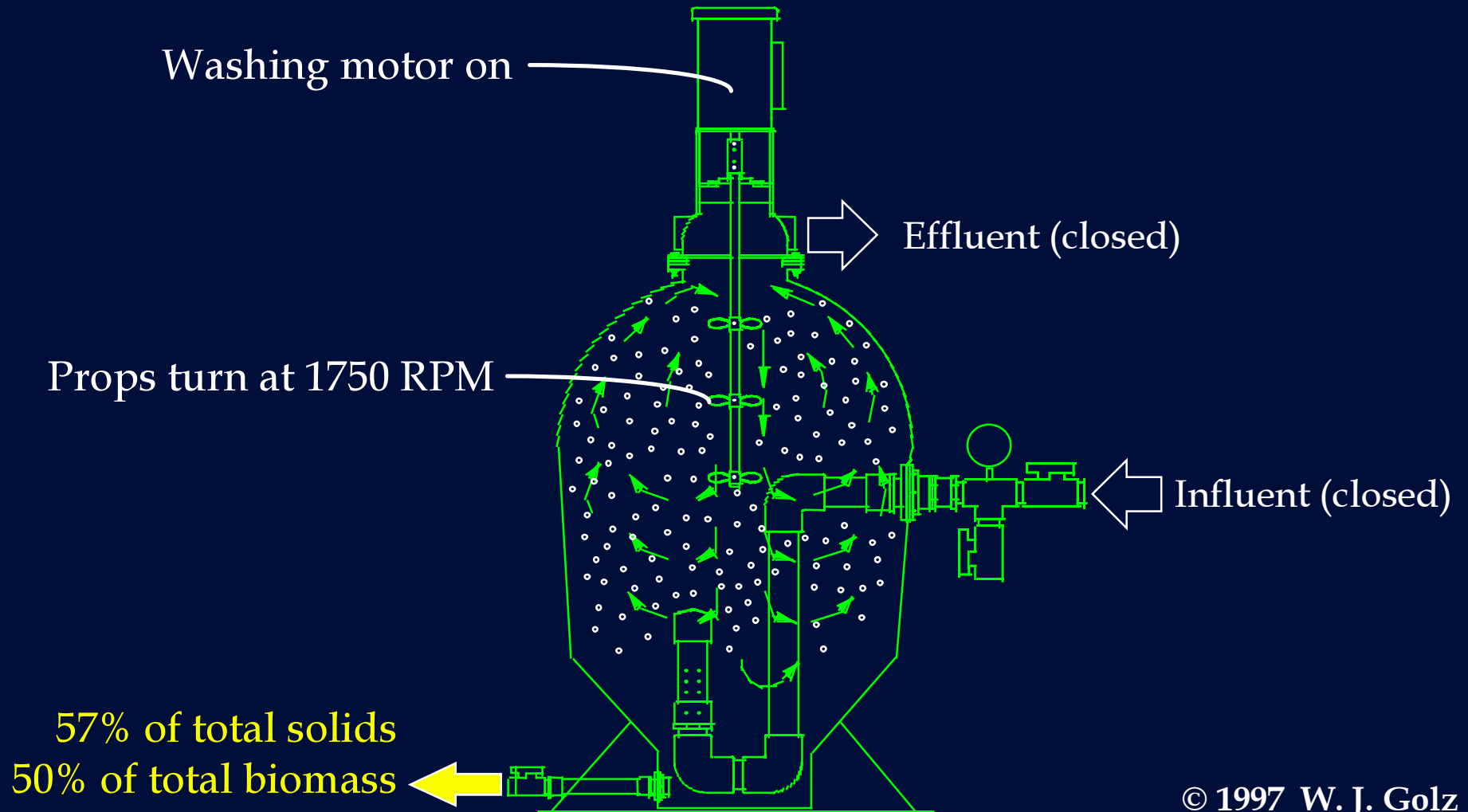
# Declining flow limits gross bacterial respiration



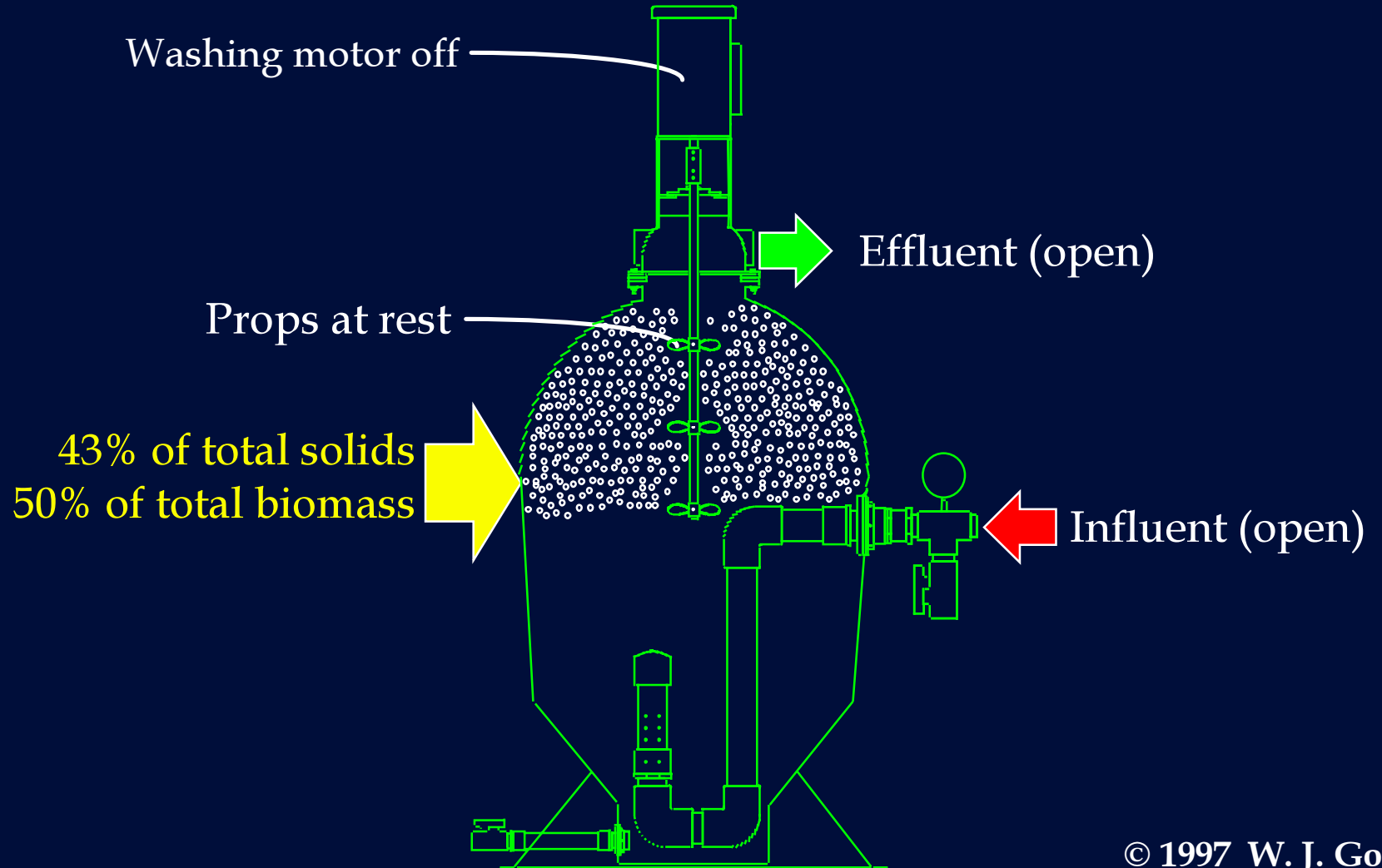
## Filter efficiency declines for longer backwash intervals



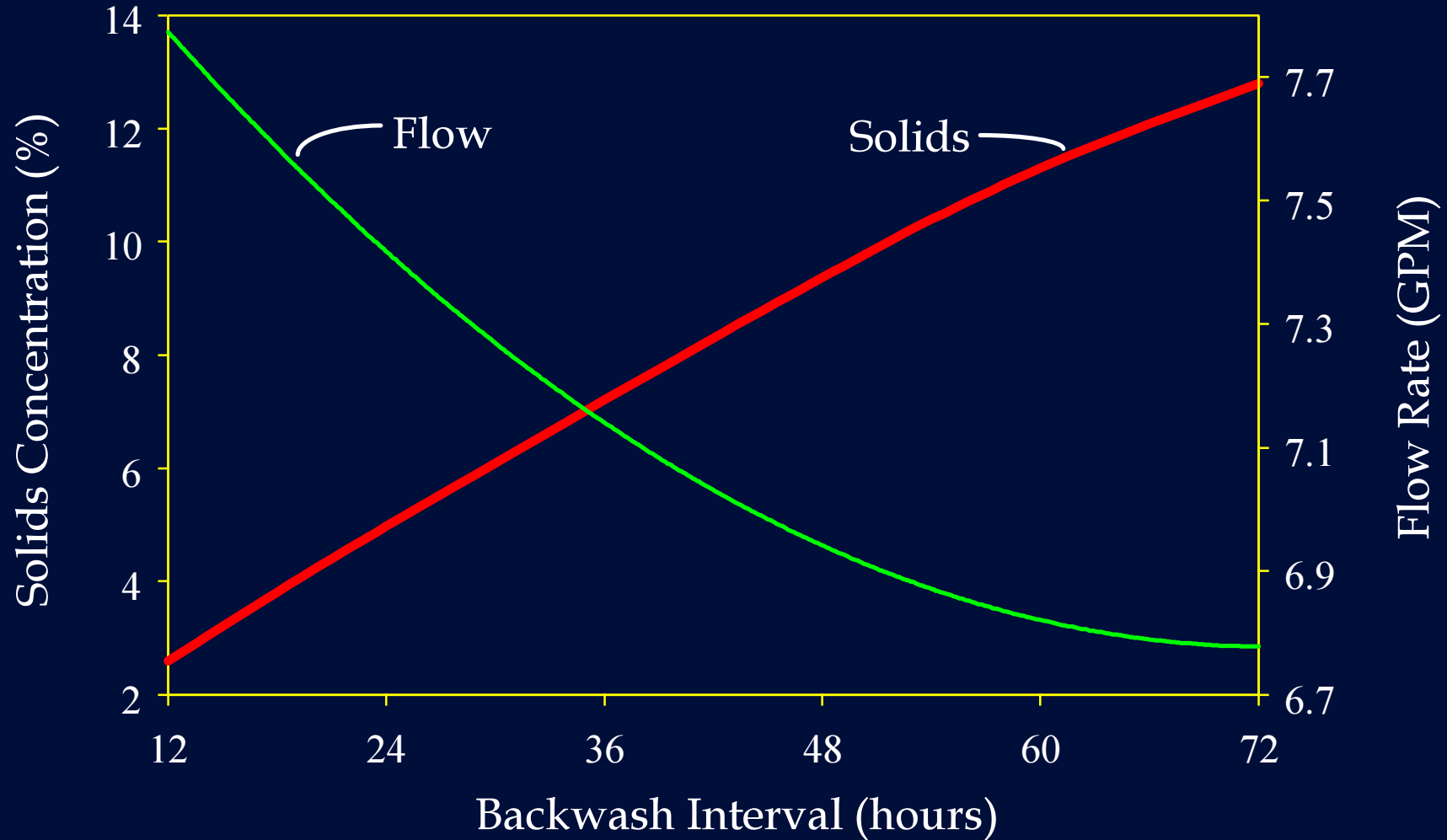
# PBF - Aggressive Mechanical Wash



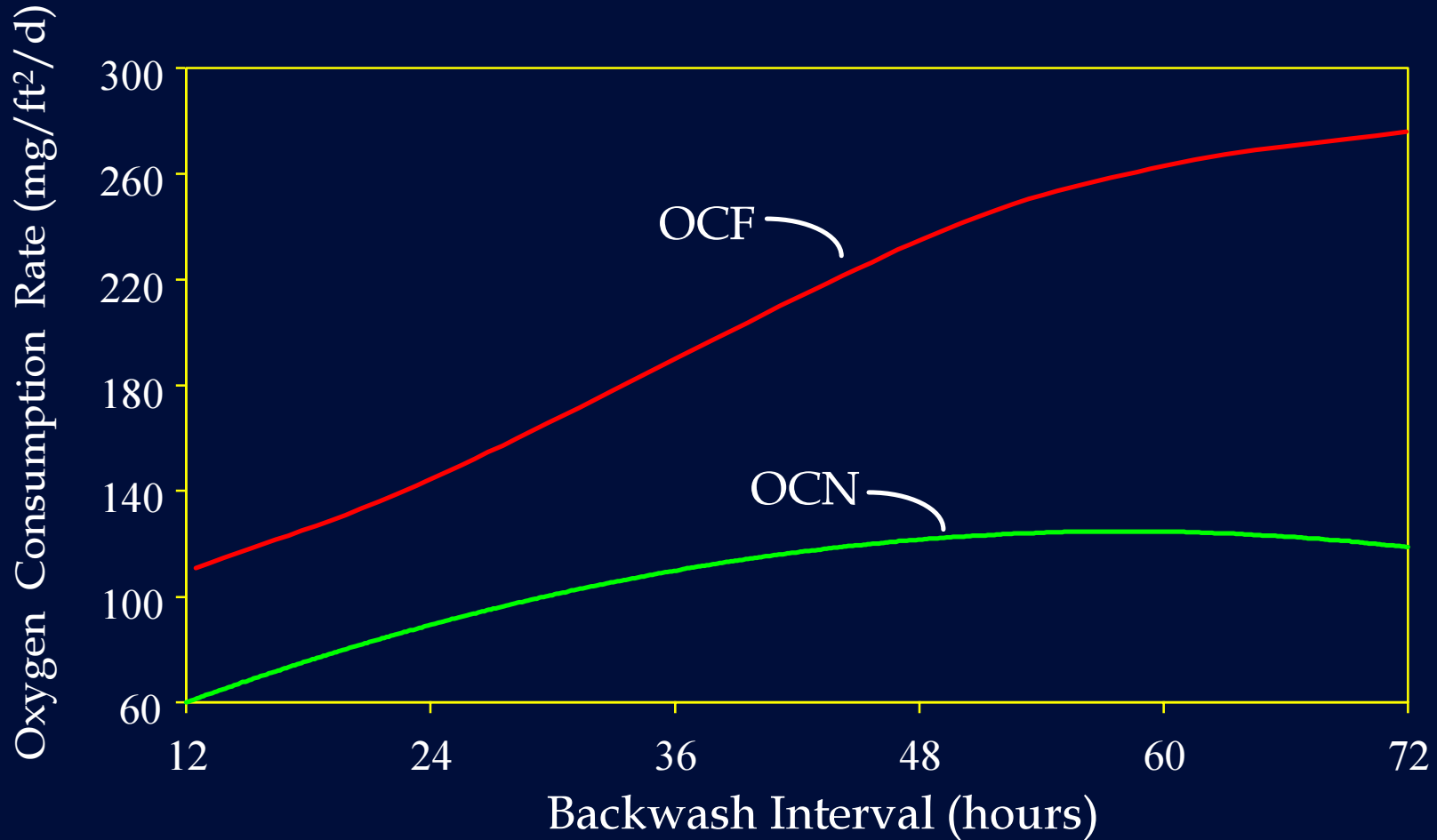
# PBF Filtration Mode



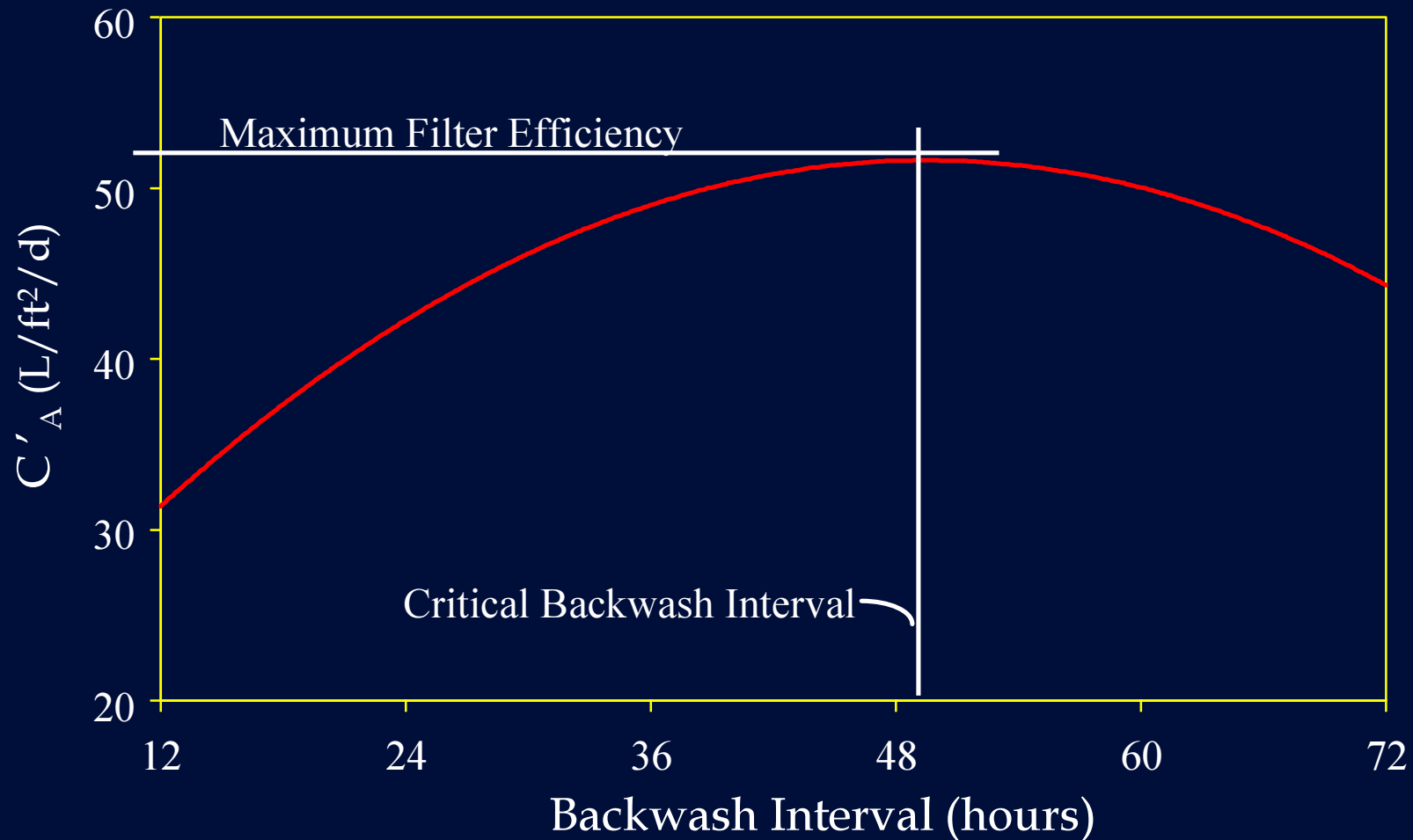
# A larger solids harvest results in lower concentrations



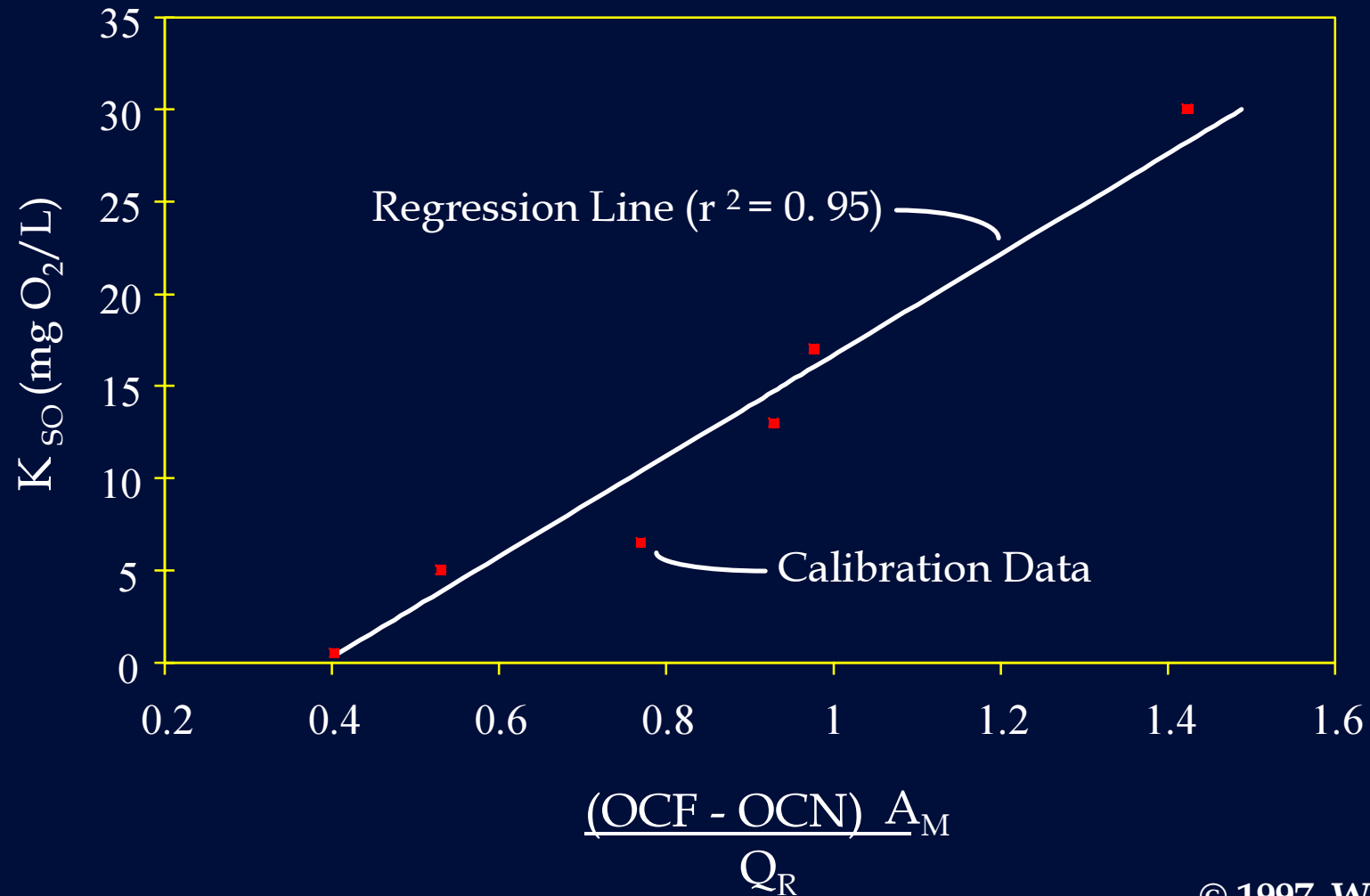
As OCF approaches an upper limit OCN declines



# Filter performance is optimal at a critical backwash interval



A relationship exists among  $K_{SO}$ , oxygen consumption, and flow





# Conclusions

- Solids limitation
  - ✗ Increases with internal loading and flow decline
  - ✗ Constraint on oxygen transfer to nitrifying bacteria
- Gently-washed filters are limited by internal loading
  - ✗ Longer biomass age and larger solids concentrations
- Aggressively-washed filters are limited by MCRT
  - ✗ Shorter biomass age and smaller solids concentrations



# Recommendations

- Filter

- ✘ Large harvest fraction - mitigate internal loading

- Media

- ✘ Higher biofilm retention - lift the MCRT limit

- ✘ Higher porosity - increased flow & biomass