Neptune and Innowatech End User Conference
27 January 2010, Congress centre Het Pand Onderbergen, Gent, Belgium

Advancements in Aerobic Granular Biomass Processes

Prof. Jurg Keller
AWMC, The University of Queensland, Australia

Andreas Giesen
DHV, The Netherlands

Overview

- Principles and Fundamentals
  - Prof. Jurg Keller – AWMC-UQ

- Application in industrial and municipal wastewater treatment
  - Andreas Giesen - DHV

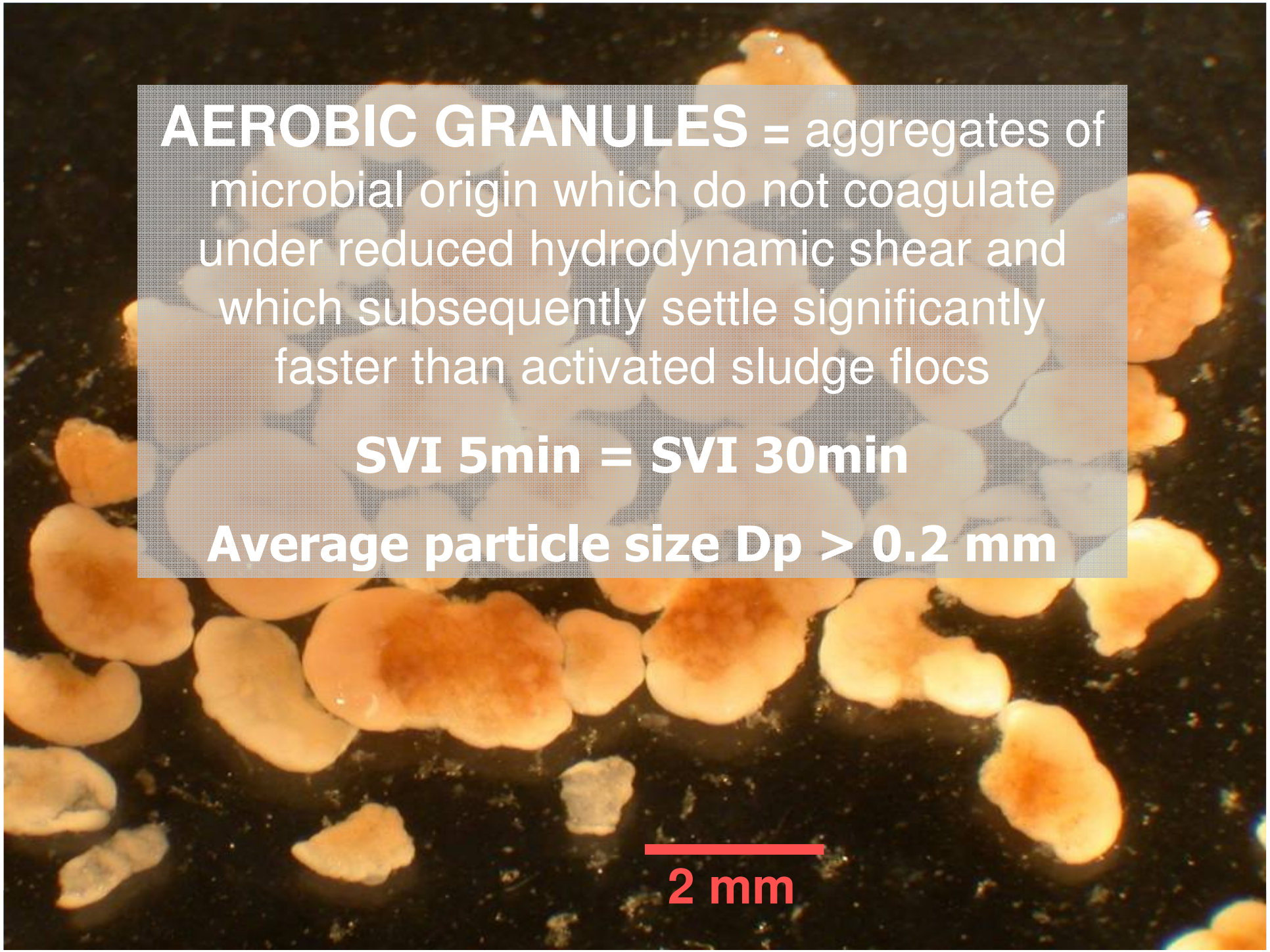
Aerobic biological treatment

Carrousel®, BASF, design 10,000,000 pe

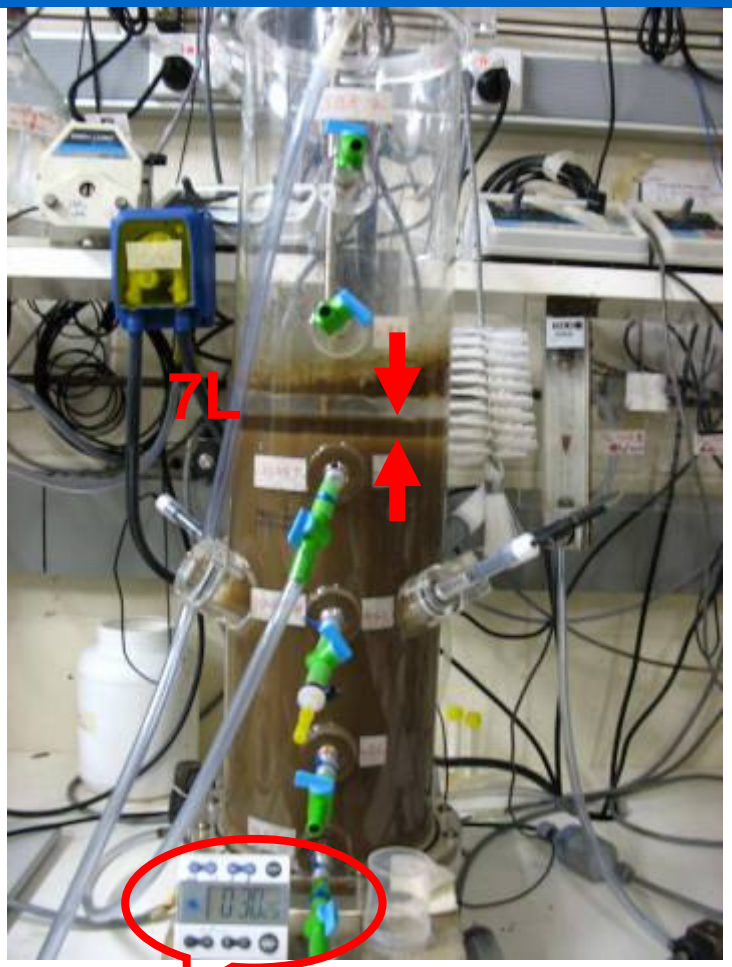
Carrousel®2000, steel mill

Conventional Activated Sludge system (CAS) is widely used for biological treatment of municipal and industrial wastewater discharges, but……

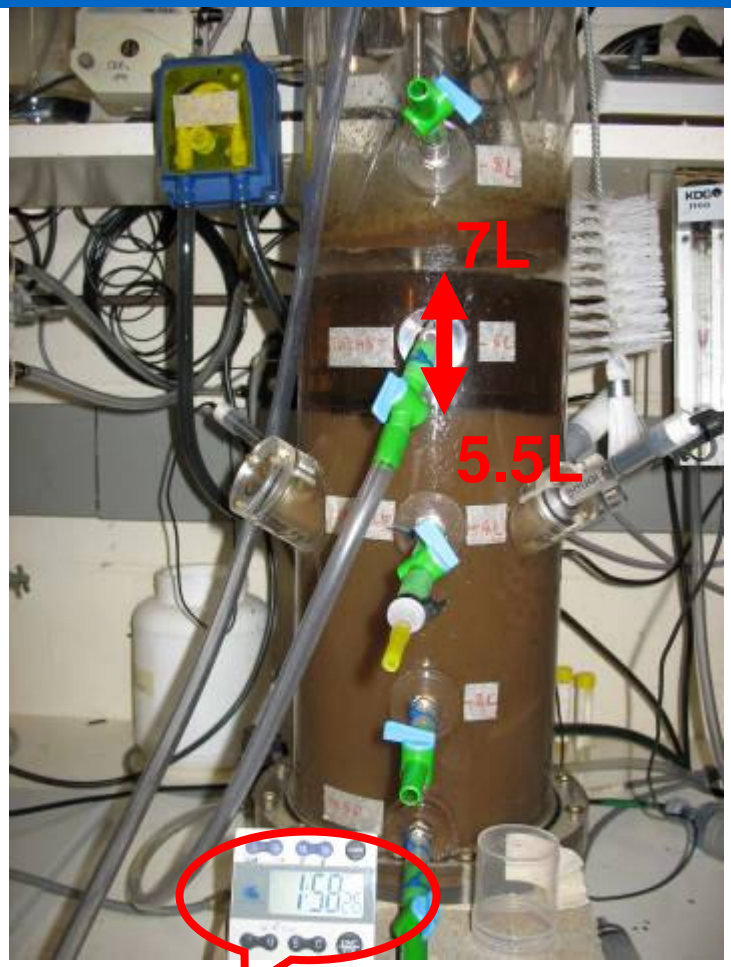
- Is sensitive towards bulking sludge
- Requires significant footprint
- Uses a considerable amount of energy
- Enhanced biological nutrient removal often leads to complex designs and operations


AEROBIC GRANULES = aggregates of microbial origin which do not coagulate under reduced hydrodynamic shear and which subsequently settle significantly faster than activated sludge flocs
SVI 5min = SVI 30min
Average particle size Dp > 0.2 mm
2 mm

Floccular sludge systems



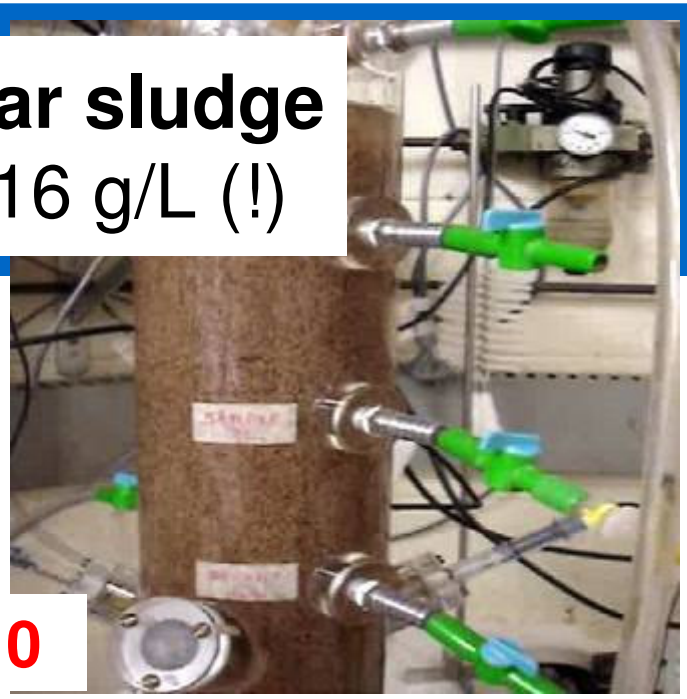
T = 30 min



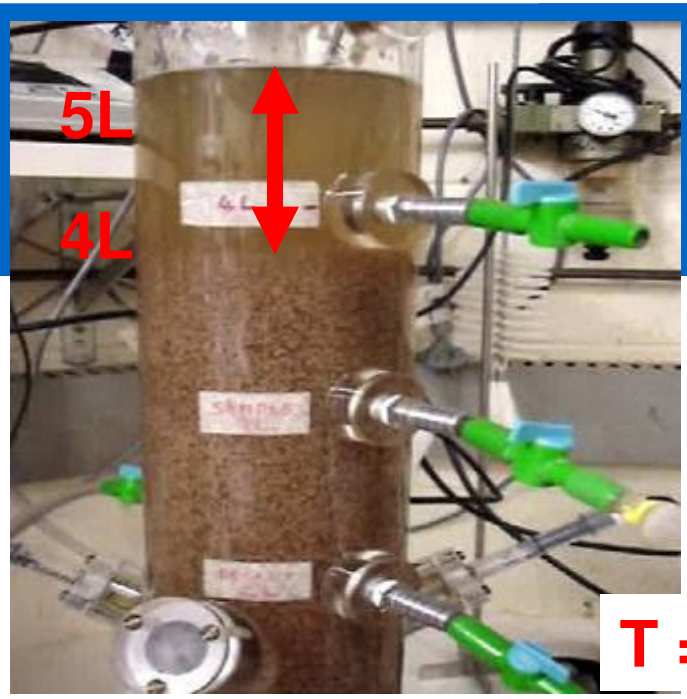
T = 2h

Granular sludge

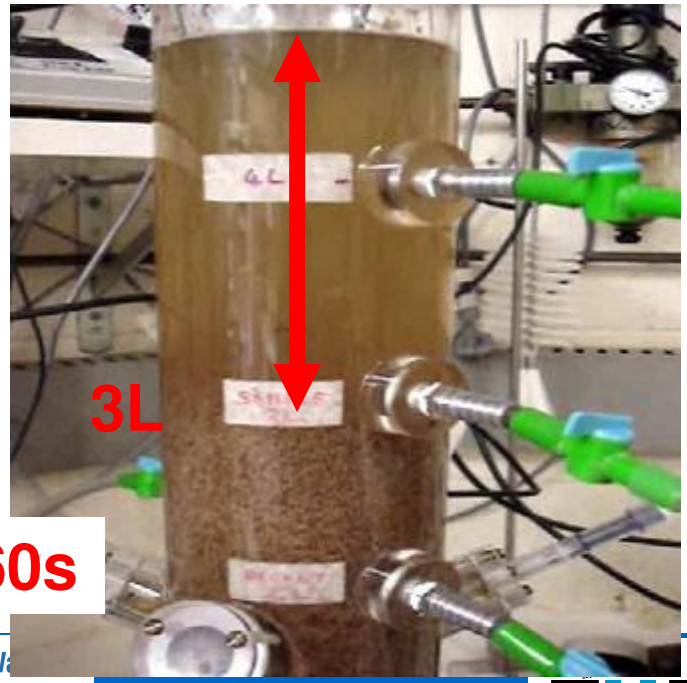
5L @ 16 g/L (!)



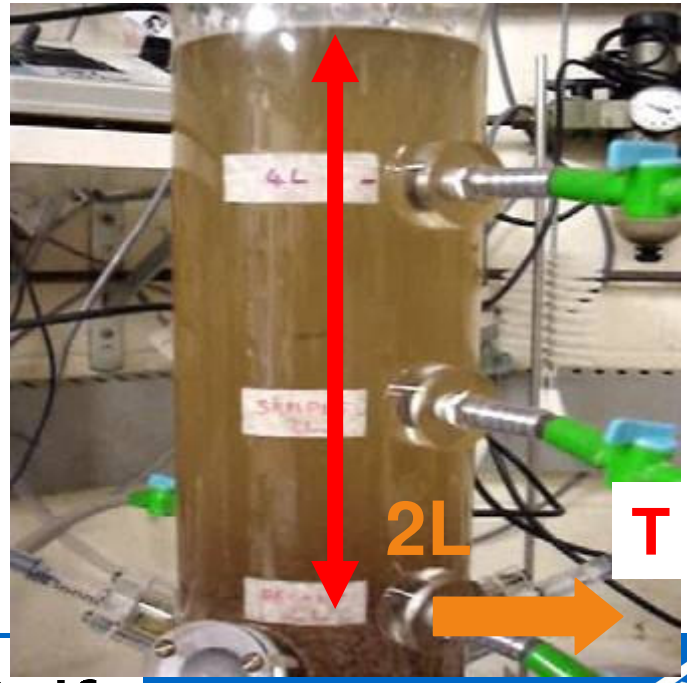
T = 0



T = 30s

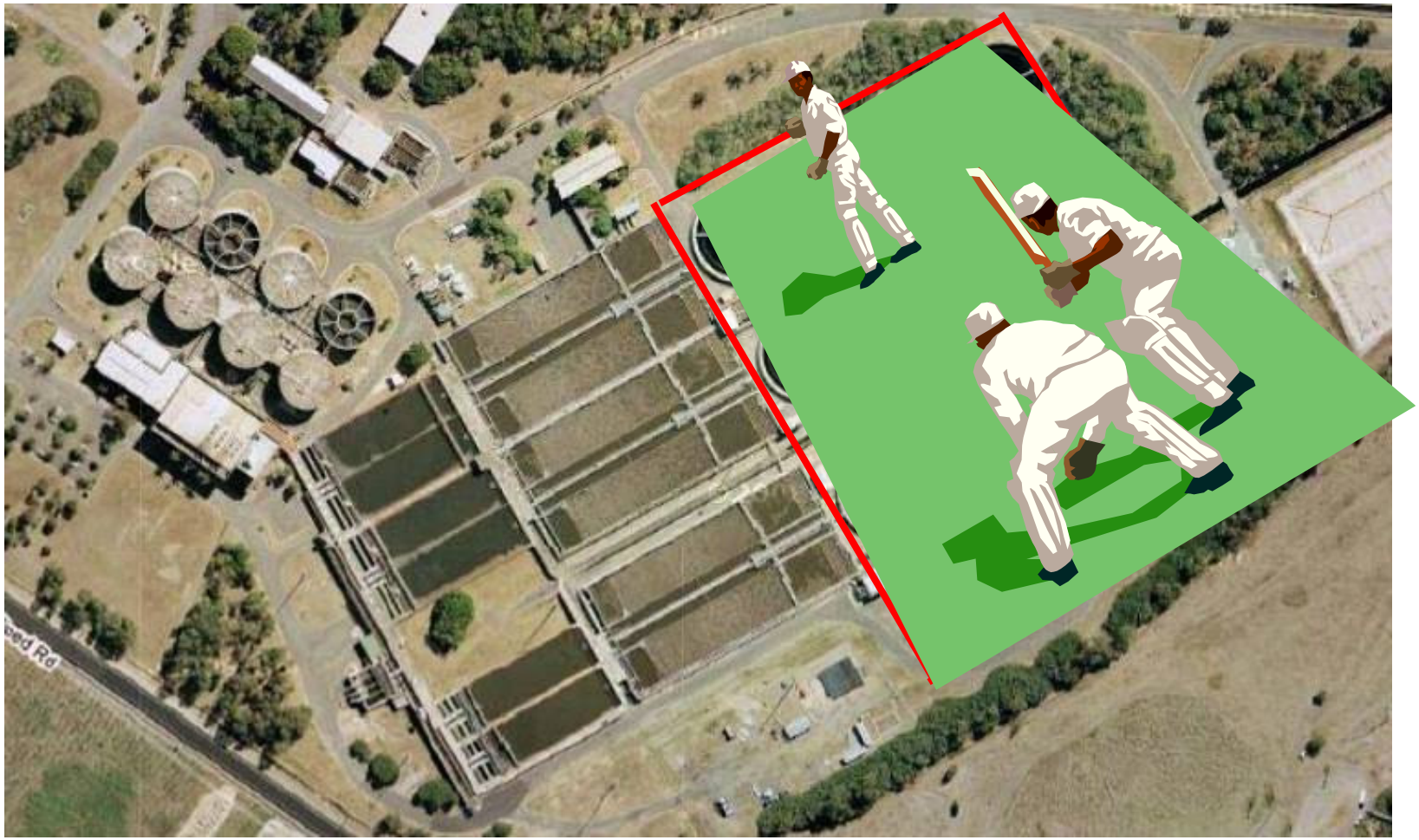


T = 60s



T = 90s

Advantages



75% smaller footprint

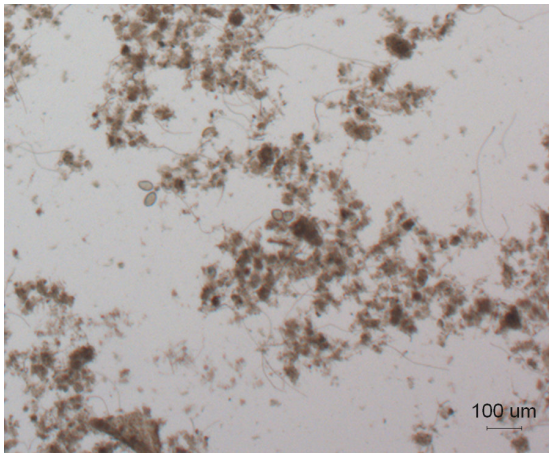
Advantages

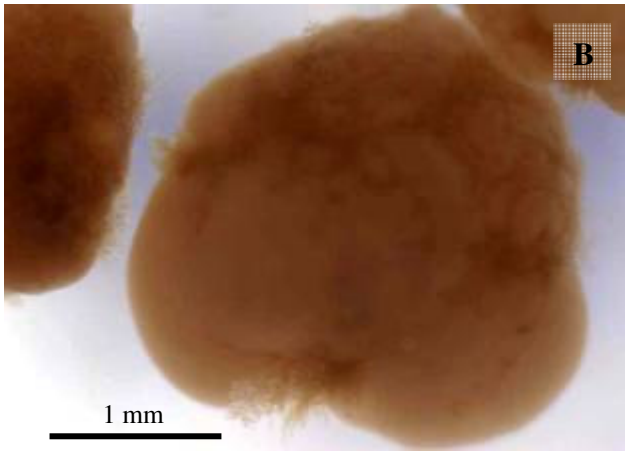
	Activated sludge process	
	Flocs	Granules
MLSS	**2-5 g/L**	10-15 g/L

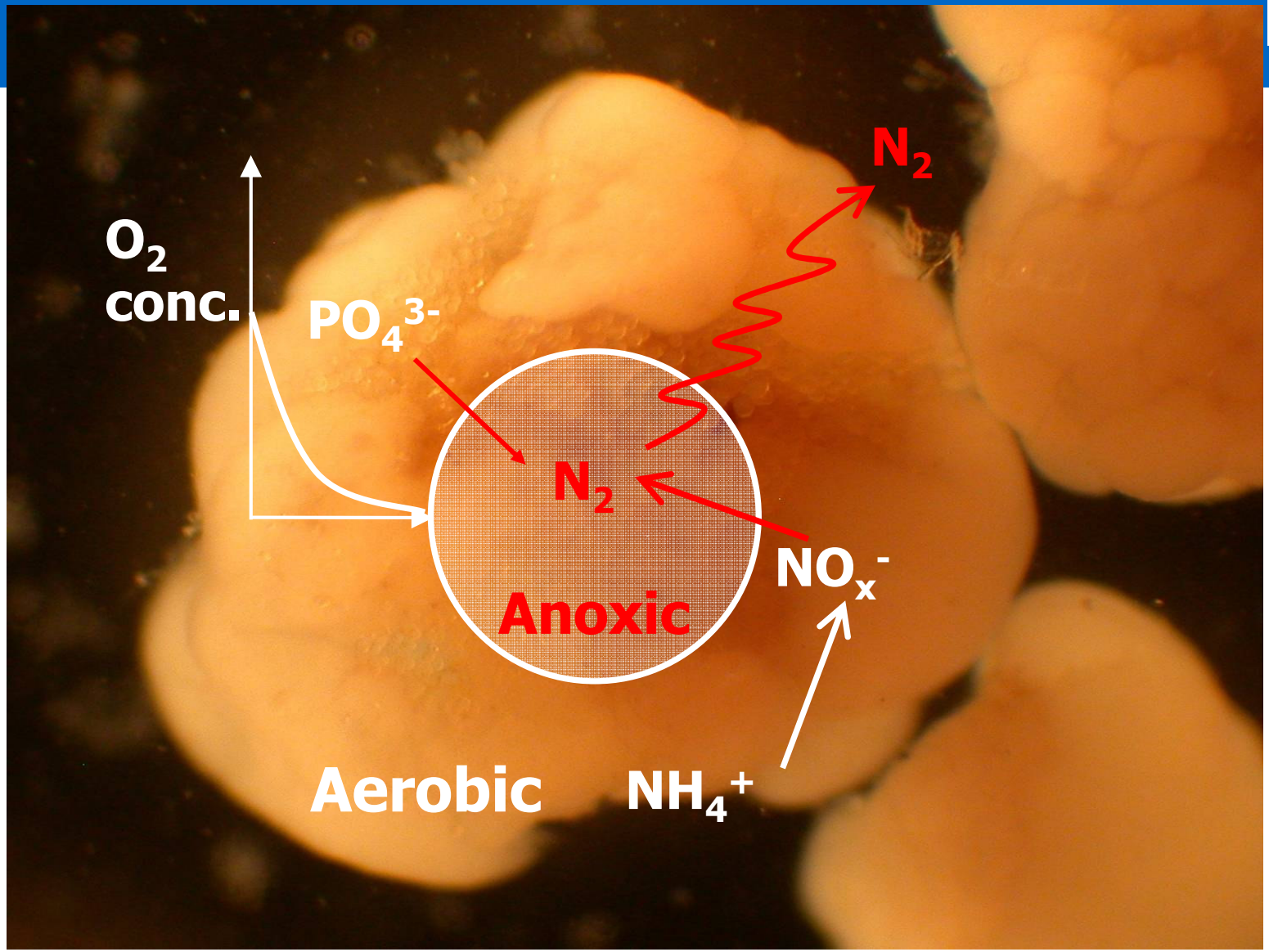
- Allow higher loading rates
- More compact reactors

Advantages

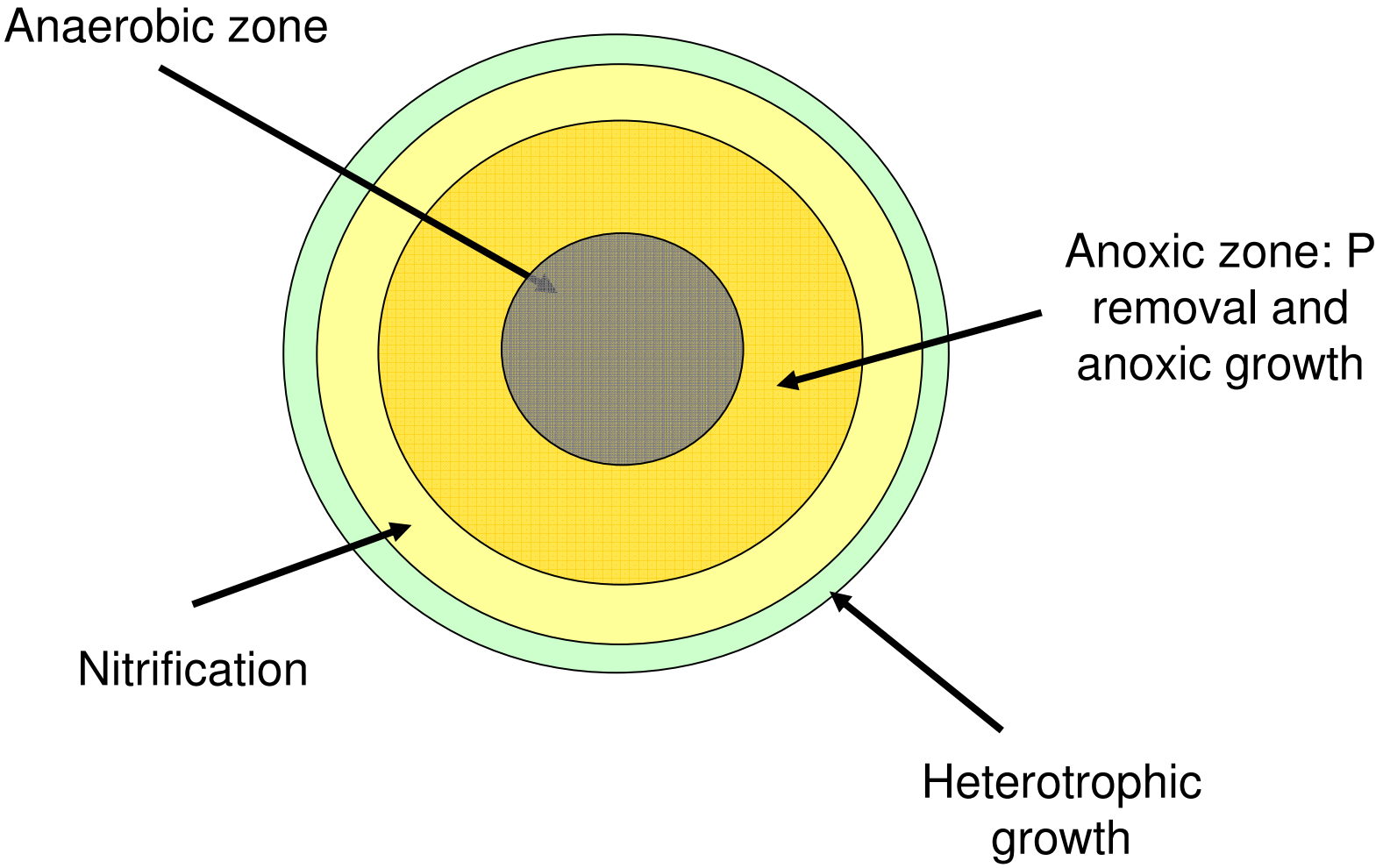
	Activated sludge process	
	Flocs	Granules
Size	**100 µm**	Up to 4 mm



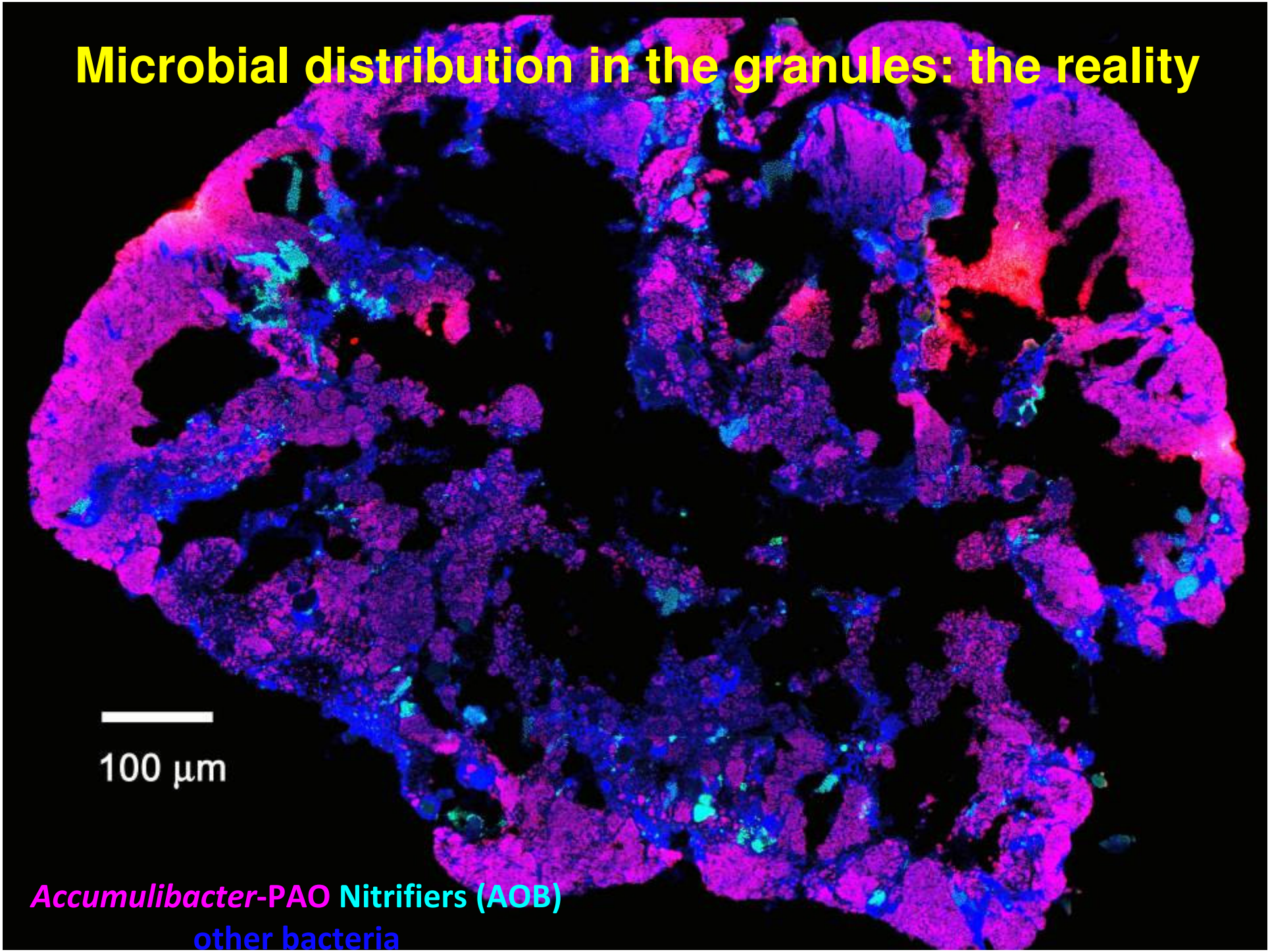



O_2 conc.
PO_4^{3-}
N_2
N_2
Anoxic
NO_x^-
Aerobic
NH_4^+

Microbial distribution in the granules: the theory



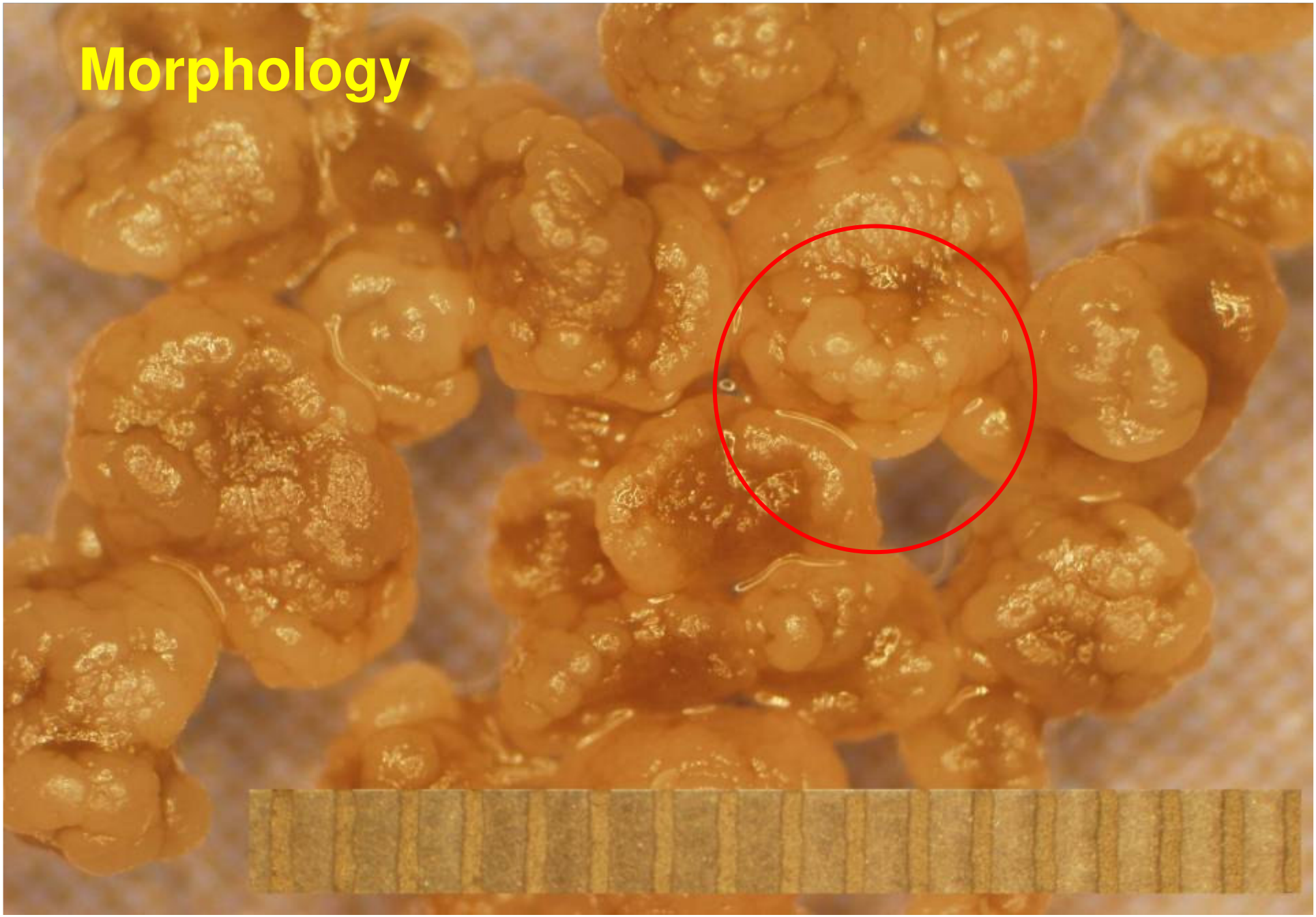
Microbial distribution in the granules: the reality



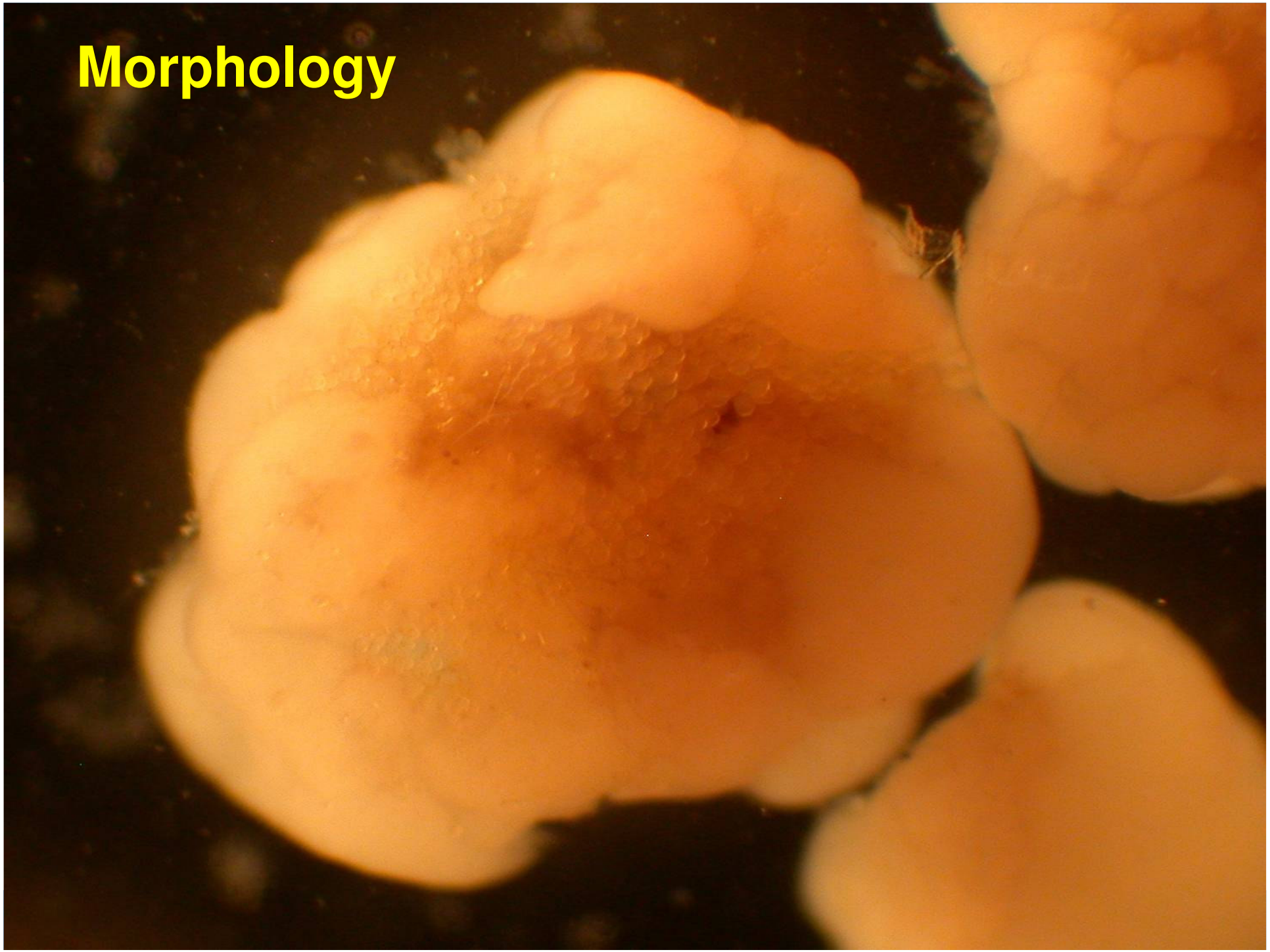
Key advantages

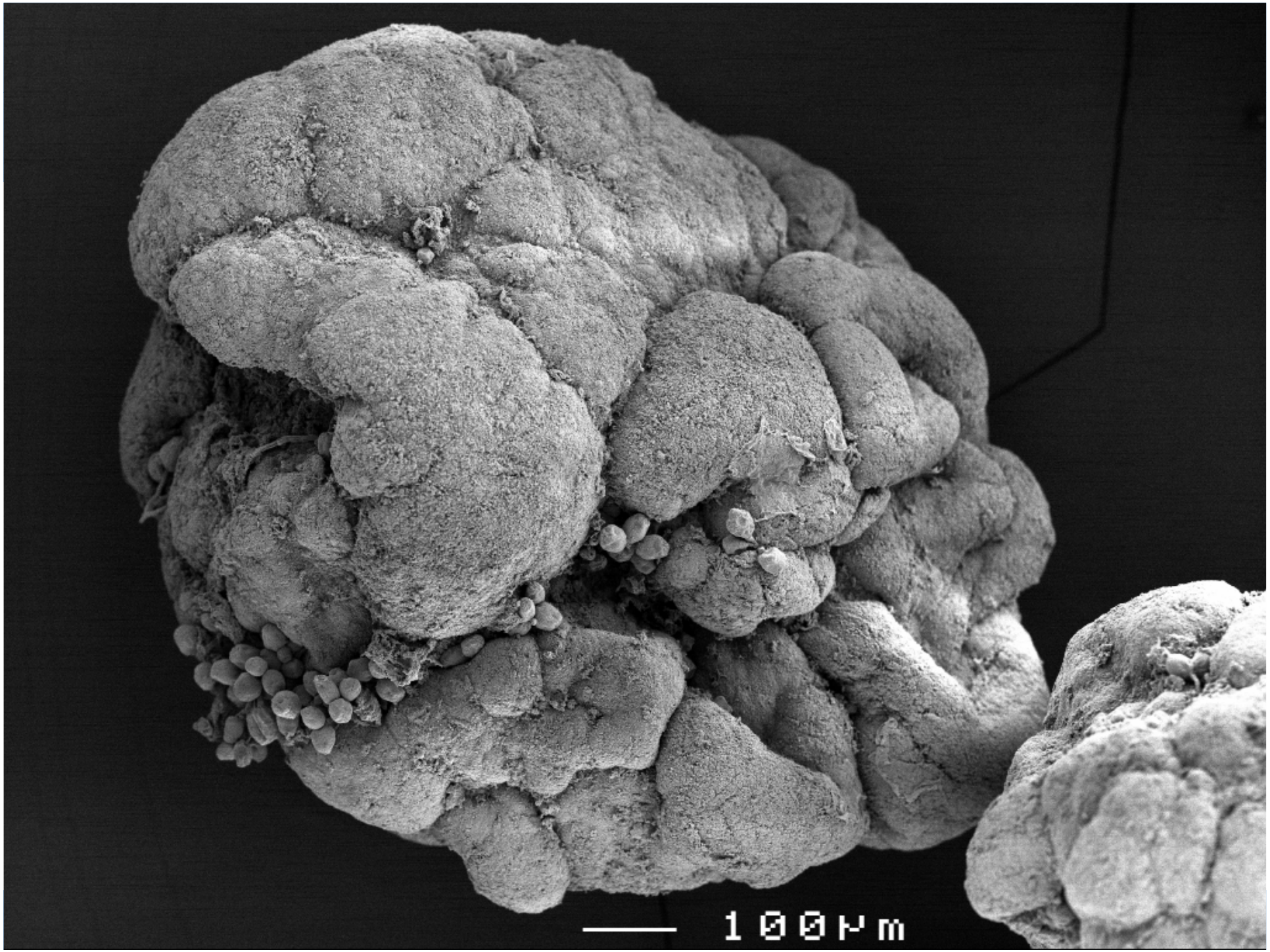
- Simultaneous biological N- and P-removal
- Simple one-tank Sequencing Batch Reactor concept (no clarifiers)
- Small footprint – high throughput
- Simple and easy operation
- Reduced energy consumption
- Alternative technology to Membrane Bioreactors
- Reduced costs

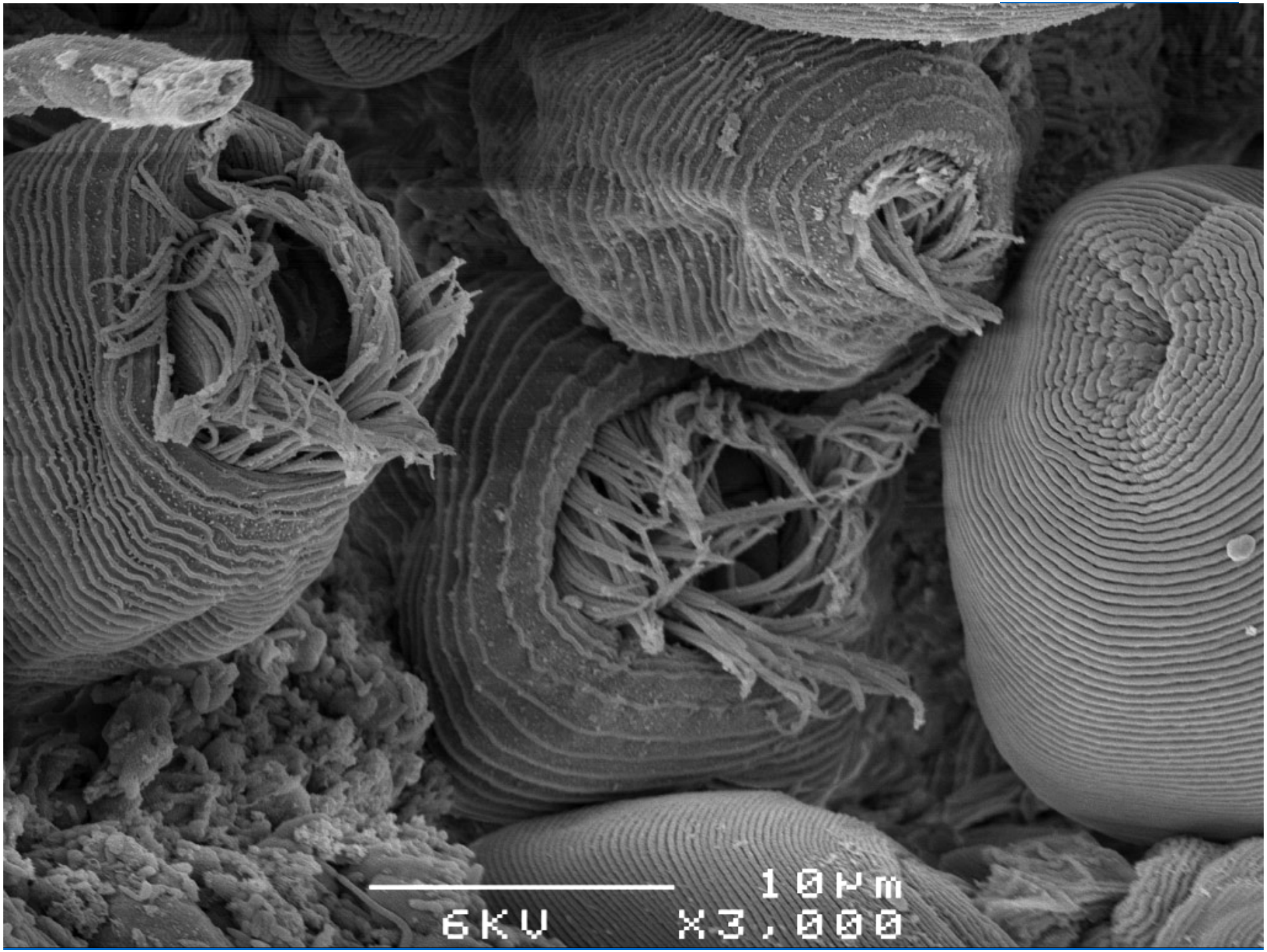
Morphology

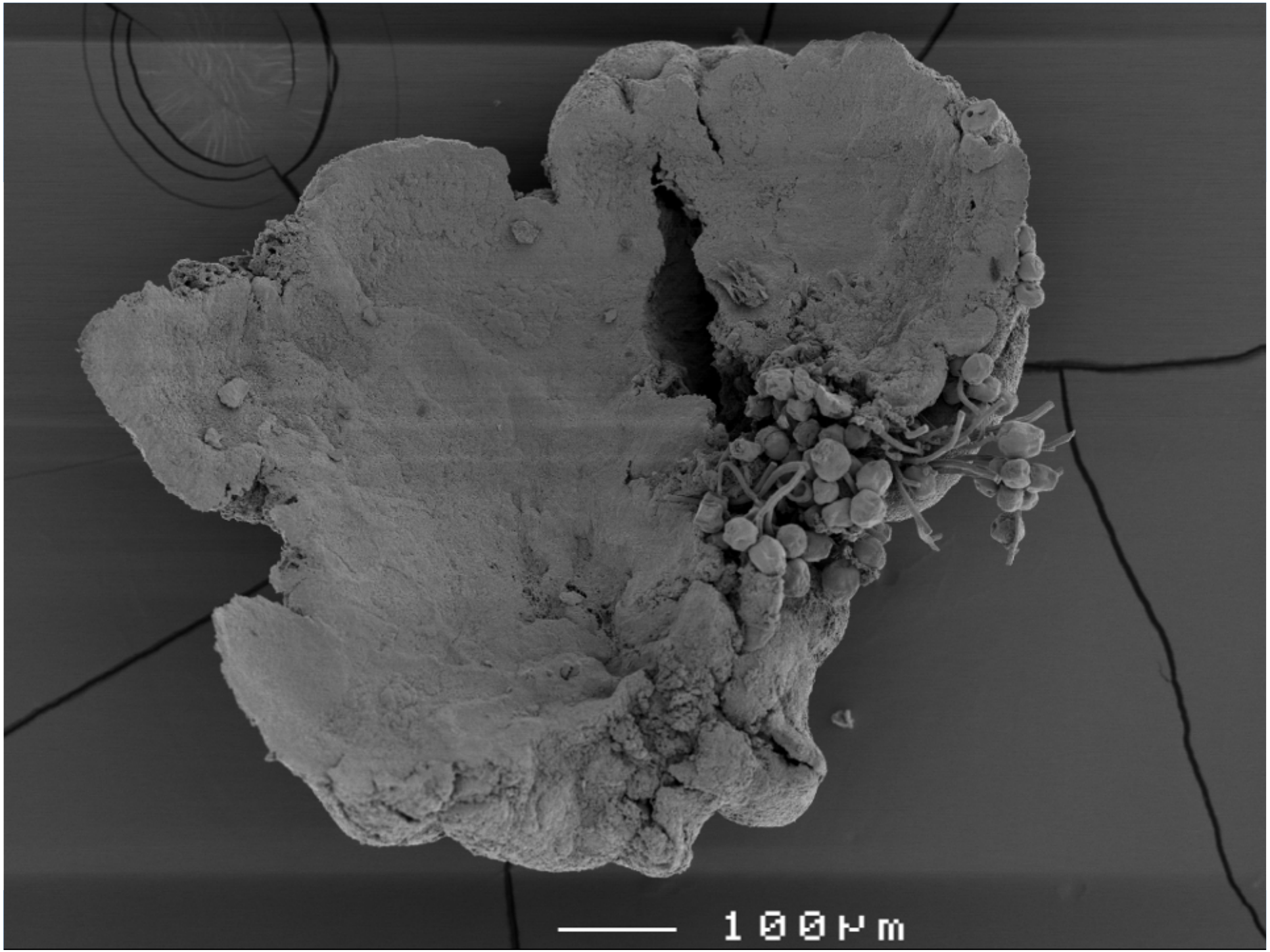


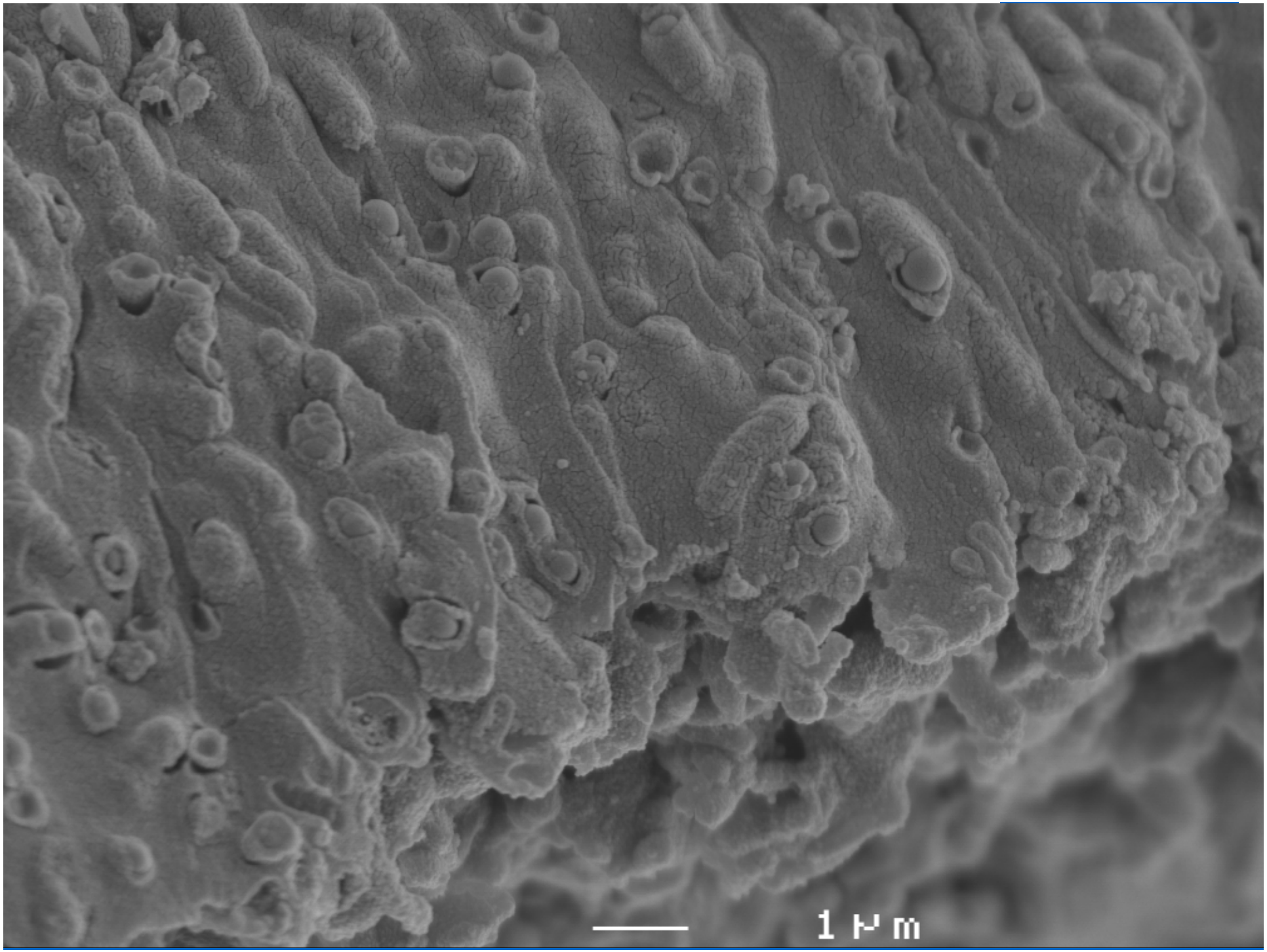
Morphology

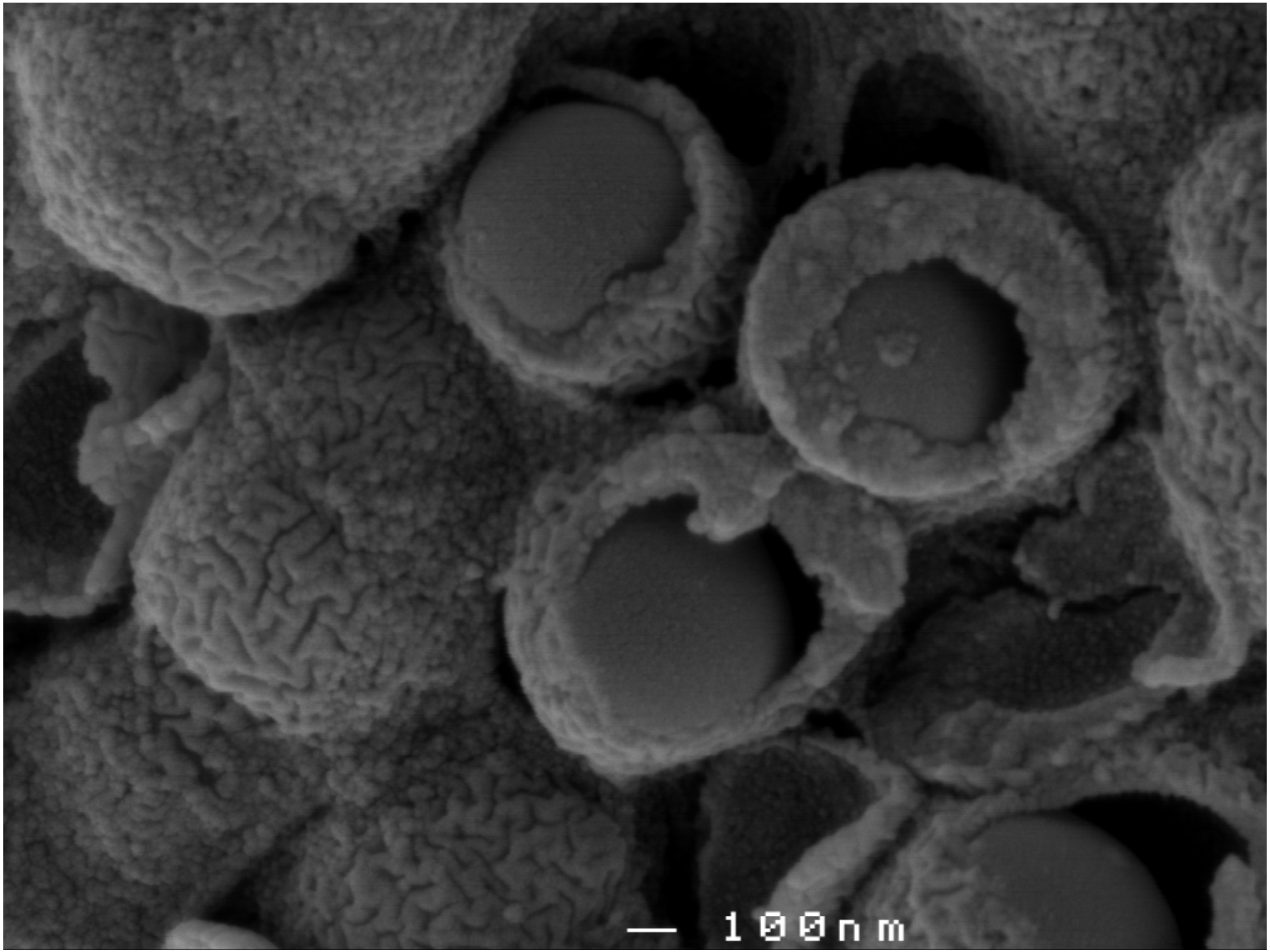



100µm


10μm
6KV X3,000


100µm


1 µm


100nm

Key Challenges

- Granule formation process slow during initial start-up
- Fundamentals of granulation process poorly understood
- Performance on challenging wastewaters unknown
- Optimisation of operational strategies required
- Long-term stability of granules under starvation unknown
- Limited experience and demonstration of technology
- Validation of actual performance at pilot/full-scale

→ **Research in Innowatech, work package 1: AWMC, TU Delft, DHV, IRSA/CNR, Wedeco**

Advanced Water Management Centre

TU Delft

DHV

DIISR - International Sciences Linkage Program

Provides funding to AWMC to join the INNOWATECH project

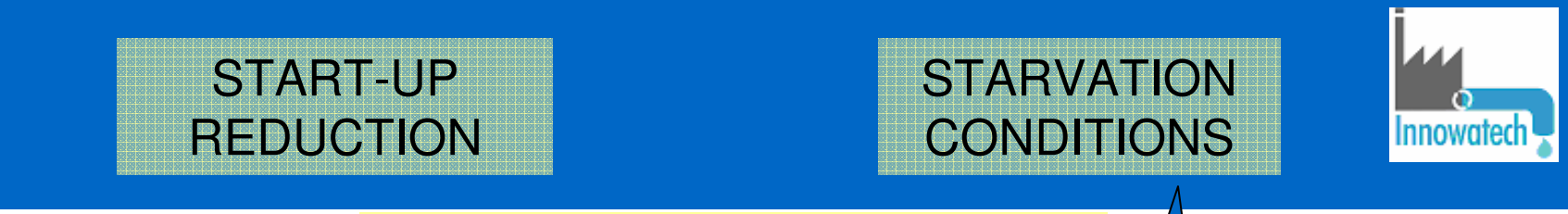
Australian Government

Department of Innovation
Industry, Science and Research

Environmental Biotechnology
Cooperative Research Centre

START-UP REDUCTION

STARVATION CONDITIONS



Applied Research

Aerobic granulation for the treatment of nutrient rich WW

WP1: AWMC

MICROARRAYS

Fundamental Research

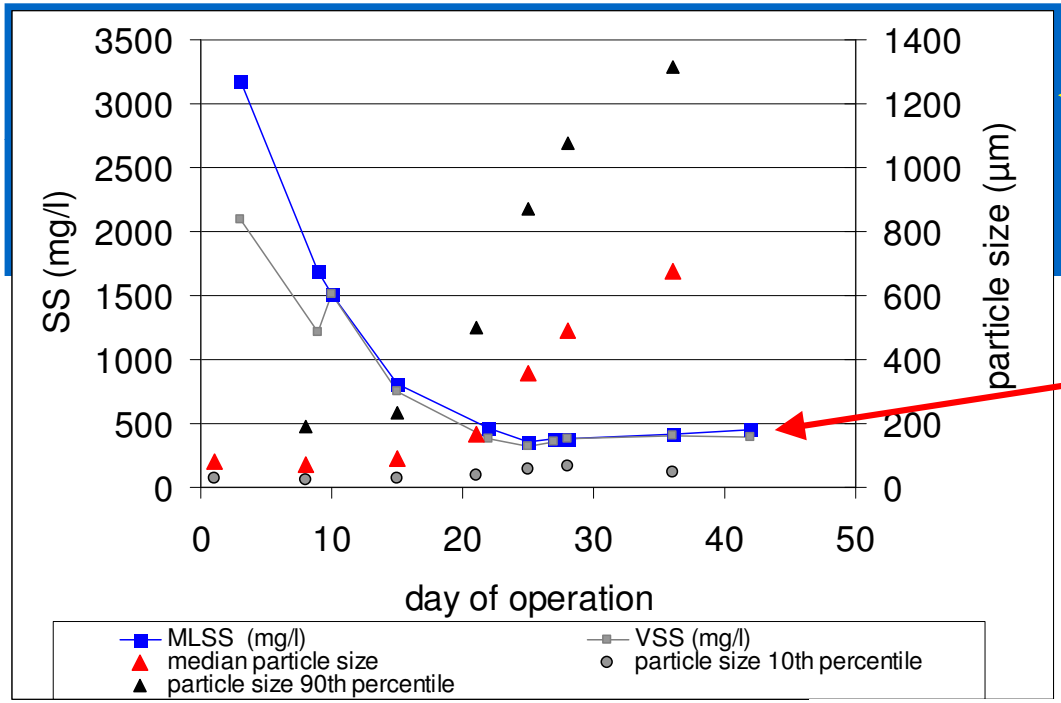
Enriched cultures to study gene expression changes during granulation

Reducing the start-up time

To achieve granulation we need:

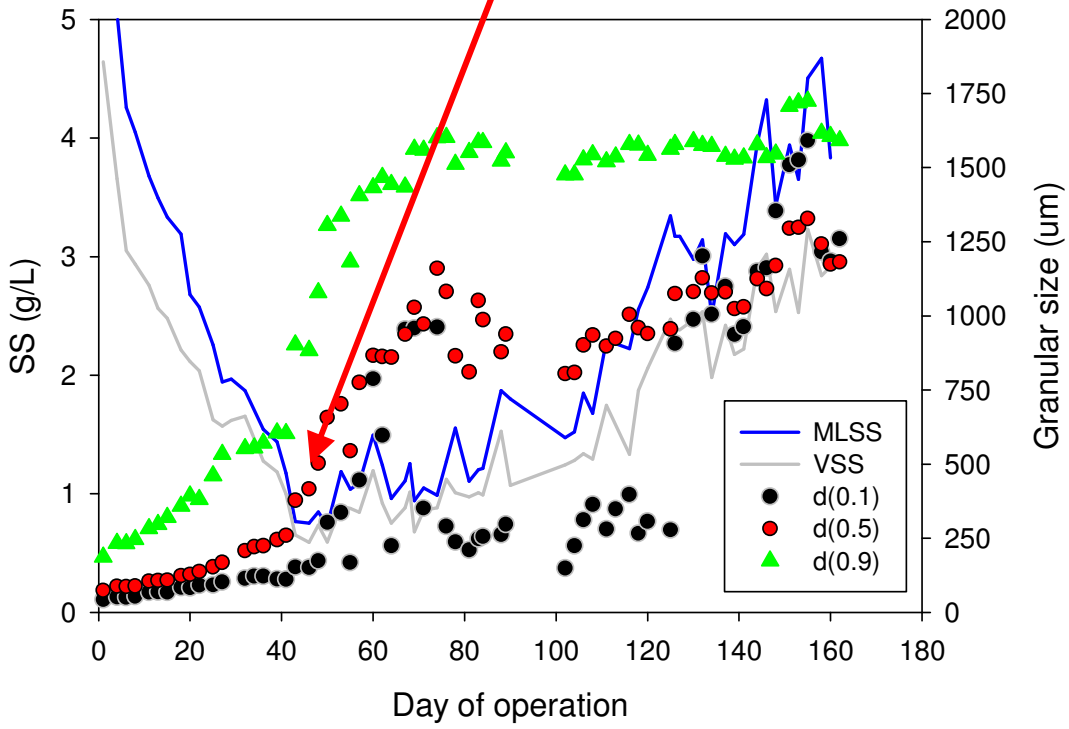
- high shear forces
- short settling time
  (selection for fast sinking, denser biomass)
- feast-famine conditions
  (pulse-feed at onset of anoxic phase, selection for slow growing bacteria)
- Avoid inhibiting conditions in concentrated wastewaters through gradual increase of NH_4^+ concentration
  (multi-stage feeding and aerobic/anoxic conditions within one cycle)

ABATTOIR WW

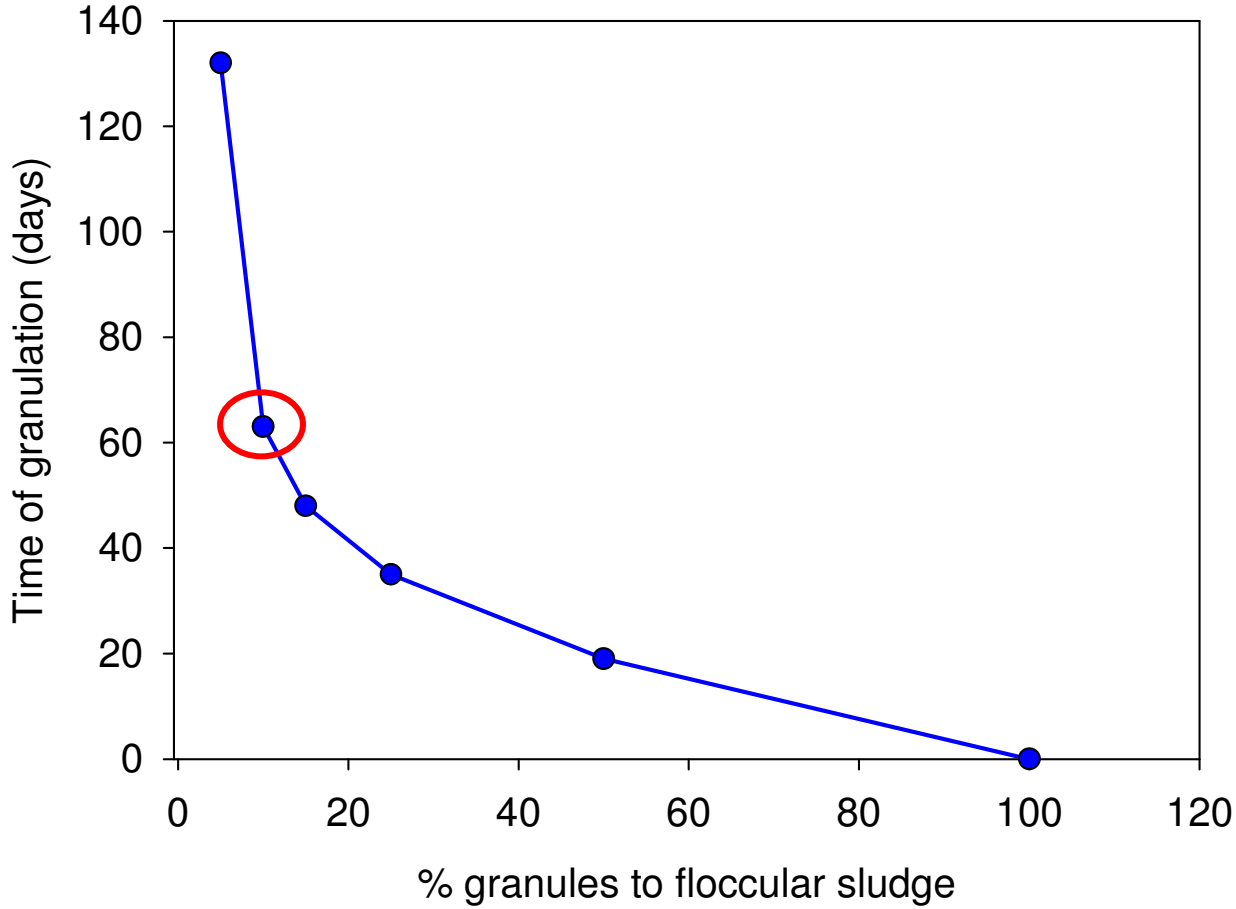


Substantial biomass loss during granulation

DOMESTIC WW



Optimisation of Seeding Sludge Mixture between Granules and Flocs



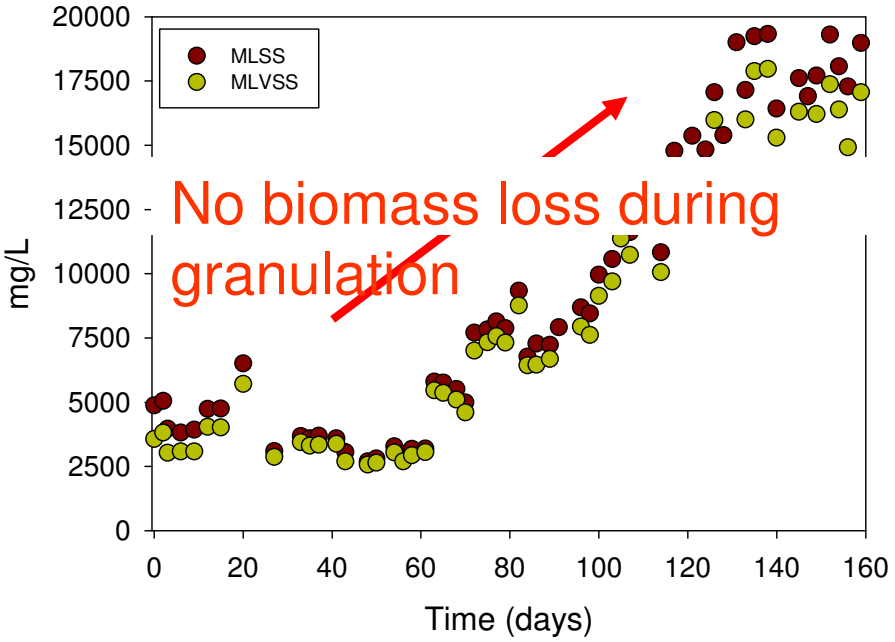
Substantial reduction on start-up times

MLSS increased during start-up

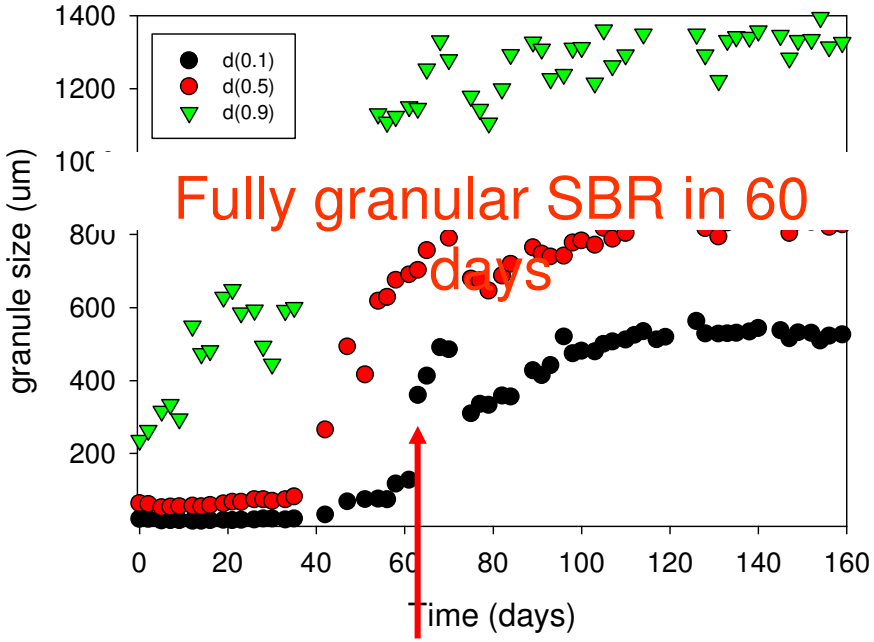
COD and N removal was achieved during start-up

Pijuan M, Yuan Z, Johns M. Reducing the start-up of aerobic granular reactors. Patent pending

10% GRANULES & 90% FLOCCULAR SLUDGE

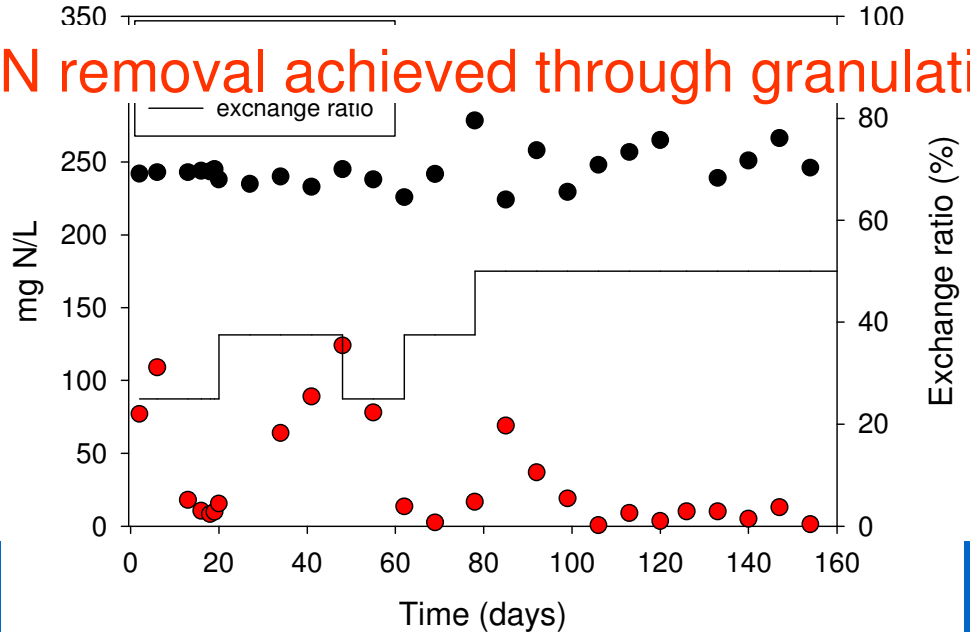


No biomass loss during granulation



Fully granular SBR in 60 days

N removal achieved through granulation

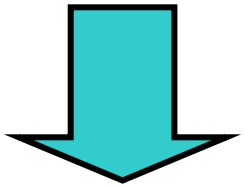


Advanced Water Management Centre

Granula Stability during Starvation

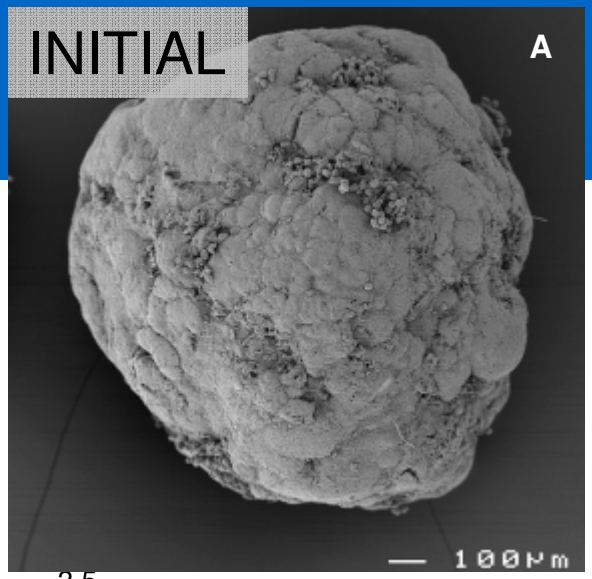
Large fluctuations of the wastewater flow

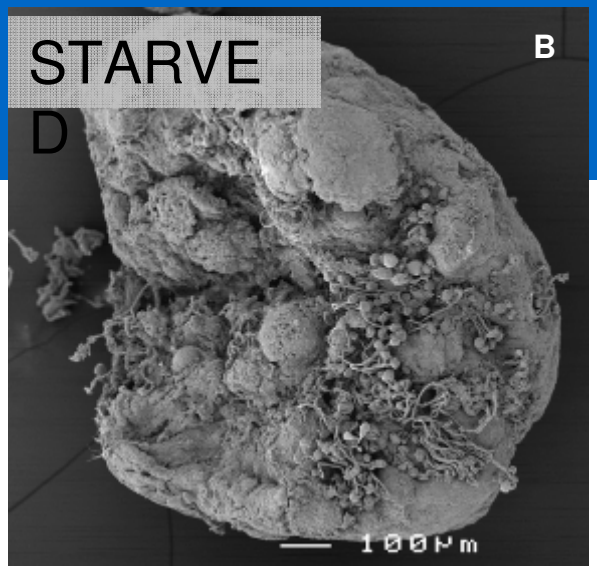
Seasonal closure of the industries

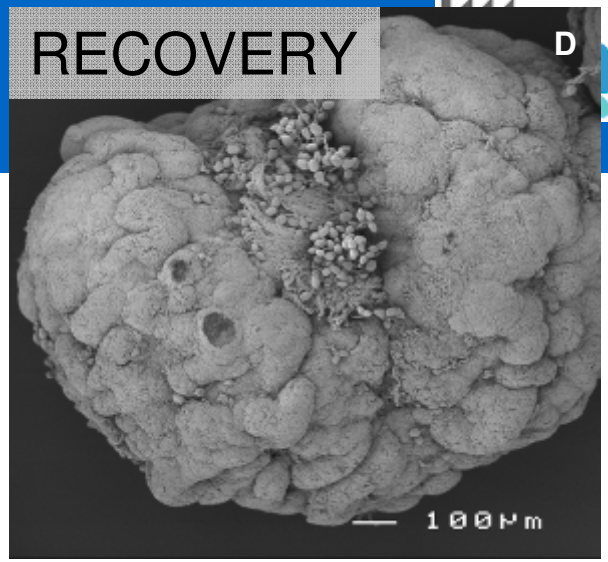


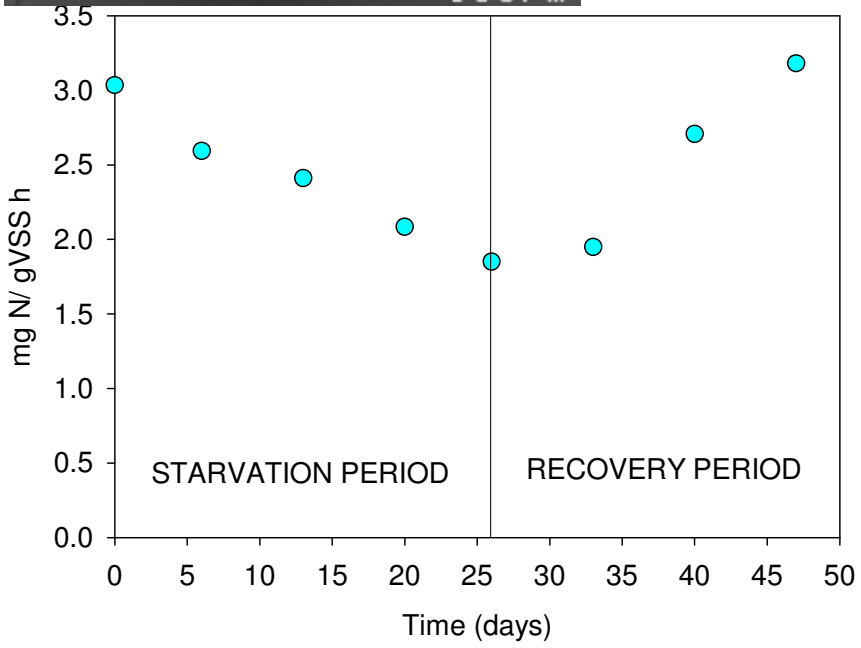
Can aerobic granules be maintained and survive under starvation conditions?

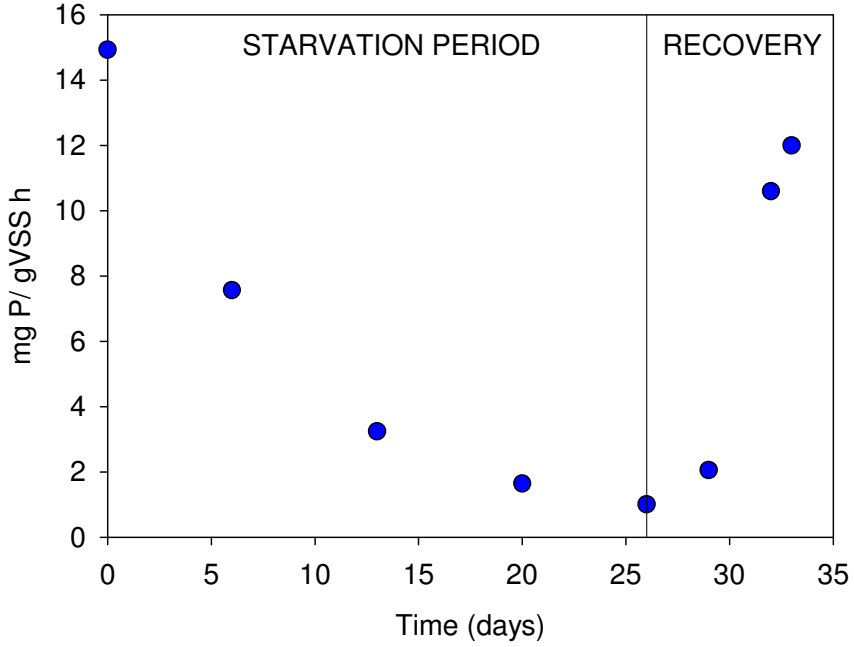
Starvation of Aerobic Granules









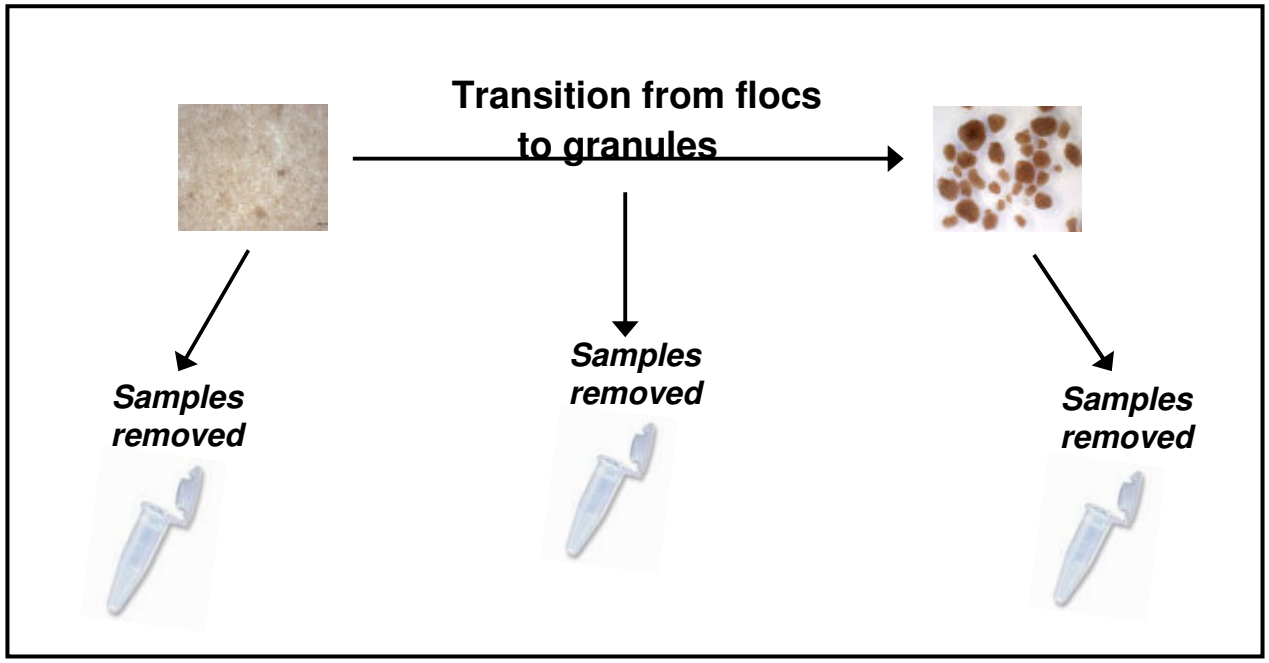


Pijuan M, Werner U, Yuan Z. Effect of long term anaerobic an intermittent anaerobic/aerobic starvation on aerobic granules. Water Research 43(14), 3622-3632.

FUNDAMENTAL RESEARCH

Microarrays to monitor changes in gene expression

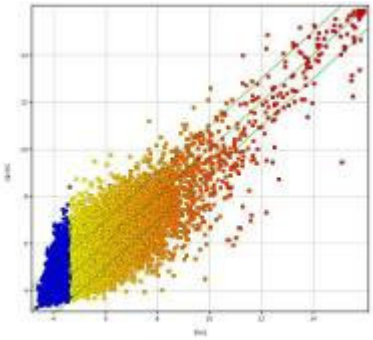
Operate reactor treating synthetic wastewater while maintaining EBPR performance



Data analysis

Filtering methods:

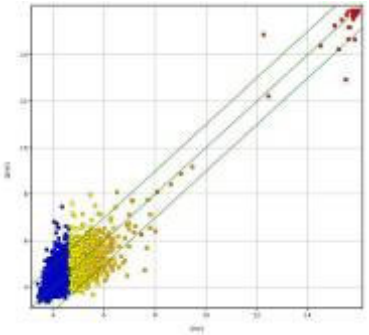
1. Standard deviation within a total condition (0.1 & 0.5)
2. Fold change between conditions (2; 3 & 5)



63595 genes

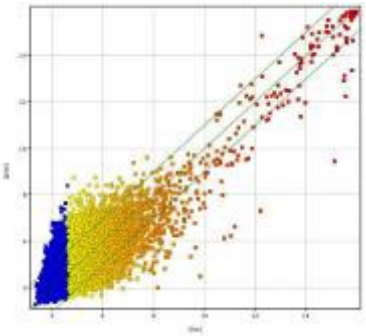
Filter 1

(0.1 Std dev.)



6858 genes

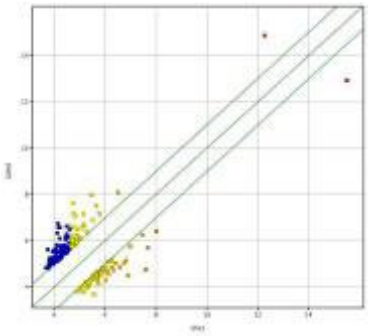
(0.5 Std dev.)



55444 genes

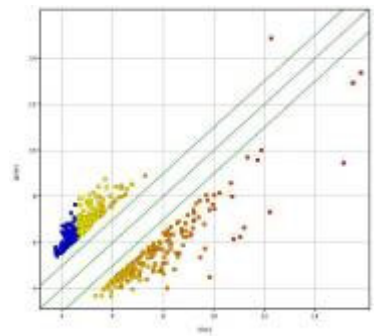
Filter 2 and statistical significance

(2 fold change)



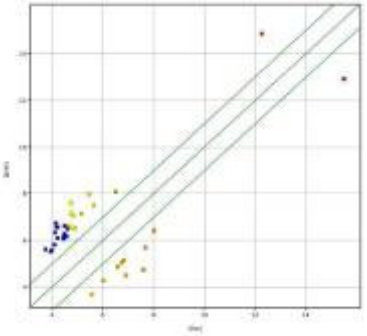
193 genes

(3 fold change)



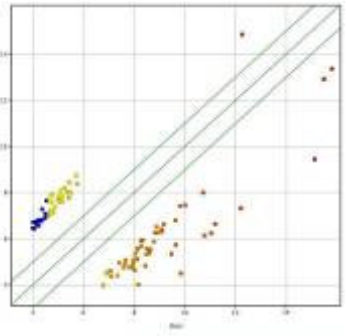
503 genes

(3 fold change)



43 genes

(5 fold change)



97 genes

Genes of interest

0.1 Std dev, 3-fold change – significant expression values

	Gene annotation (10/43 genes shown)
2000244590	Predicted enolase-phosphatase 629..823(+) [Sludge/US, Phrap Assembly]
2000219900	Adenylosuccinate lyase 84..686(-) [Sludge/US, Phrap Assembly]
2000120280	Tfp pilus assembly protein, ATPase PilU 2114..2359(-) [Sludge/US, Phrap Assembly]
2000013830	Cell division GTPase 746..1123(+) [Sludge/US, Phrap Assembly]
2000549310	Apolipoprotein N-acyltransferase 854..1397(+) [Sludge/Australian, Phrap Assembly]
2000336250	858..1046(-) [Sludge/US, Phrap Assembly]
2000431900	ABC-type tungstate transport system, permease com ponent 8642..9466(-) [Sludge/ Australian, Phrap Assembly]
2000145480	HrpA-like helicases 3..2273(+) [Sludge/US, Phrap Assembly]
2000437460	10861..11760(-) [Sludge/Australian, Phrap Assembly]
2000146890	UDP-N-acetylmuramyl pentapeptide phosphotransfera se/UDP-N-acetylglucosamine-1-phosphate transferase 4018..5244(+) [Sludge/US, Phrap Assembly]

Analysis of these genes is underway to identify in which metabolic pathways they are involved

SIXTH FRAMEWORK PROGRAMME

Innowatech

Applications of Aerobic Granule Technology

For advanced biological wastewater treatment

THE UNIVERSITY OF QUEENSLAND AUSTRALIA

Advanced Water Management Centre

TU Delft

DHV

DHV

Consultancy and Engineering

- 5,500+ staff
- Markets
  - Transportation
  - Building and Manufacturing
  - Water
  - Aviation
  - Metal & Mining
  - Spatial Planning and Environment
- Services
  - Management consultancy and advisory services
  - Design and engineering
  - Project and contract management
  - Operations management
  - Total solutions

Technology status

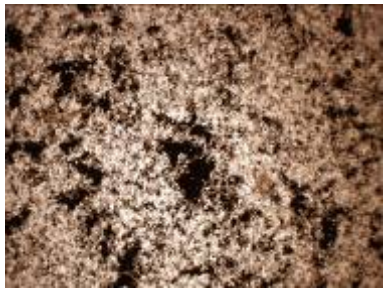
- Rather new breakthrough technology
- Much scientific interest
- Internationally limited semi-technical experience (mainly Australia, The Netherlands, South-Africa, Portugal, Italy)
- Limited but growing number of full-scale applications (Nereda®)

Advanced Water Management Centre

TU Delft

Principle of Nereda®

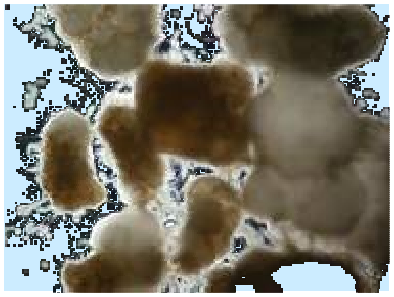
activated sludge



encourage change in biomass structure

transformation

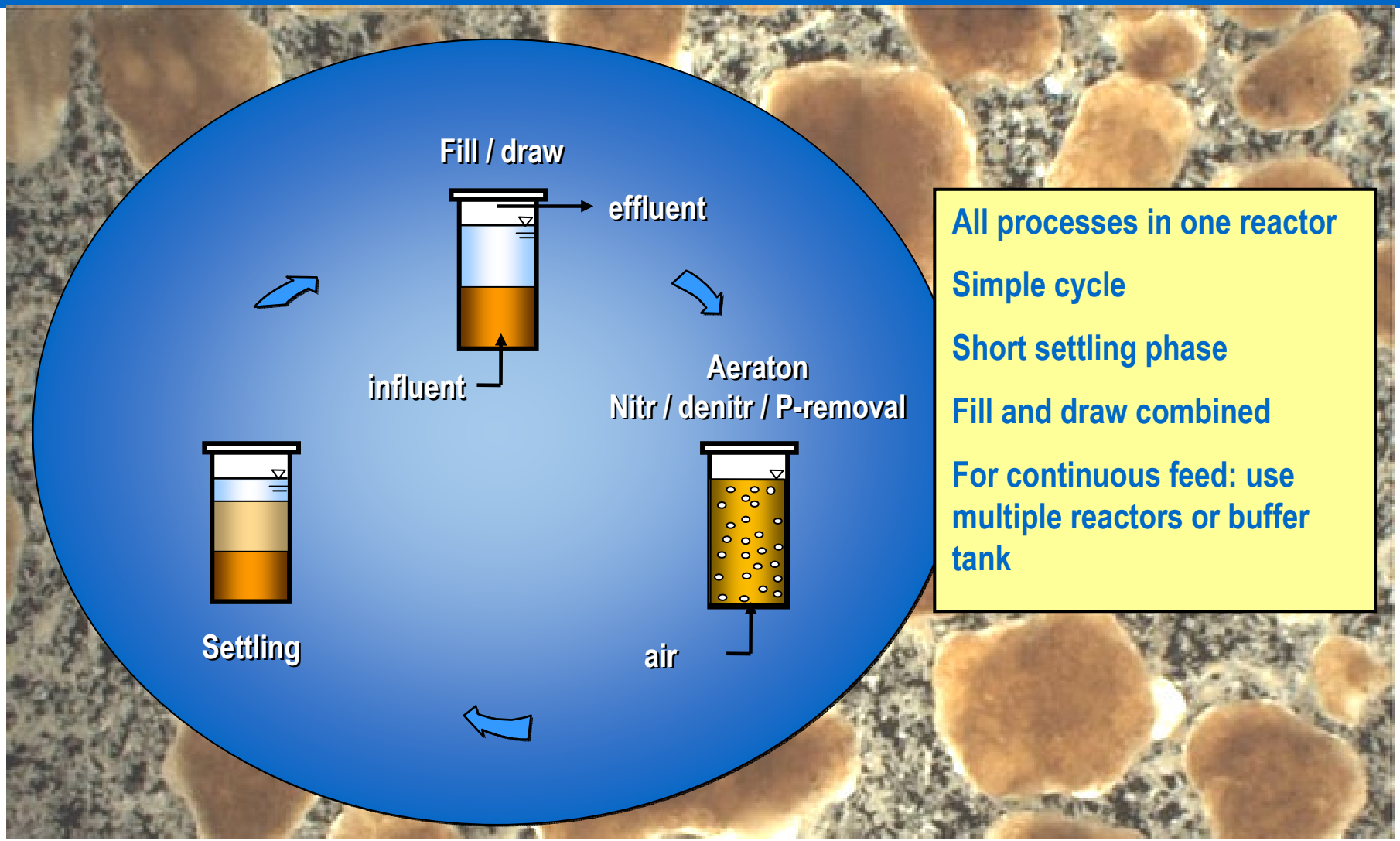
aerobic granules



Advantages:

- Excellent settling properties
- Low energy consumption
- High biomass concentration
- Sustainable technology
- Low investment and operational costs
- Simultaneous biological N- and P-removal
- Simple one-tank concept (no clarifiers)
- Small footprint
- Simple and easy operation
- Pure biomass, no support media required

Nereda® process



All processes in one reactor

Simple cycle

Short settling phase

Fill and draw combined

For continuous feed: use multiple reactors or buffer tank

Current technology status

- Industrial units in operation since 2006
- Several municipal demo units, under which
  - Portugal (3 MLD)
  - South Africa (4 MLD full-scale demo)
- Many in various preparatory state

(pre-design → pilot validation → detailed design → tender)

Cheese speciality industry

- Launching customer
- Cheese speciality industry
- Retrofit of existing storage tank
- Start-up end 2005
- Wastewater
  - 50 – 250 m^3/day
  - COD 2,000 - 4,000 mg/l
  - 1,500 – 5,000 p.e.
- Pre-treatment with grease removal and screening

Ready-made-food industry

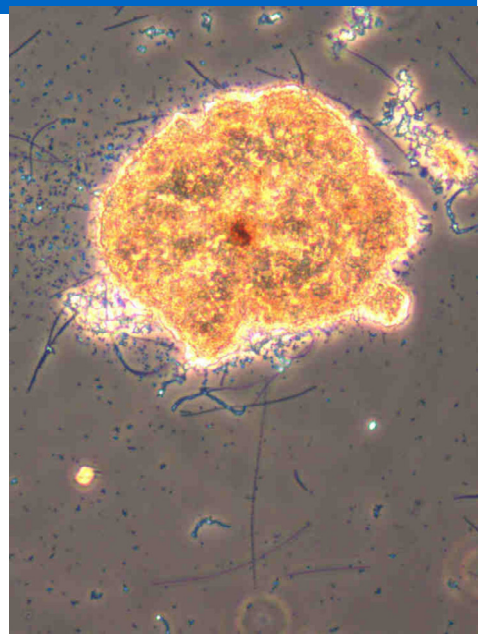
- First greenfield plant
- Start-up: June 2006
- Wastewater
  - Max. 360 m^3/day
  - COD 4,500 mg/l
  - 5,000 (design) – 10,000 p.e. (actual)
- Pre-treatment: grease removal / screening
- After factory closure in 2009, company moved plant to another production facility and doubled capacity
- Re-start-up: End 2009

Retrofit SBR eatable oil industry

- Quite old conventional SBR with severe bulking sludge problems

- Temporary rebuild Aug 2007
- Results:
  - No bulking problems
  - Stable and reliable operation
  - Significant performance improvement

- Decision Jan 2010: replace old plant with new one

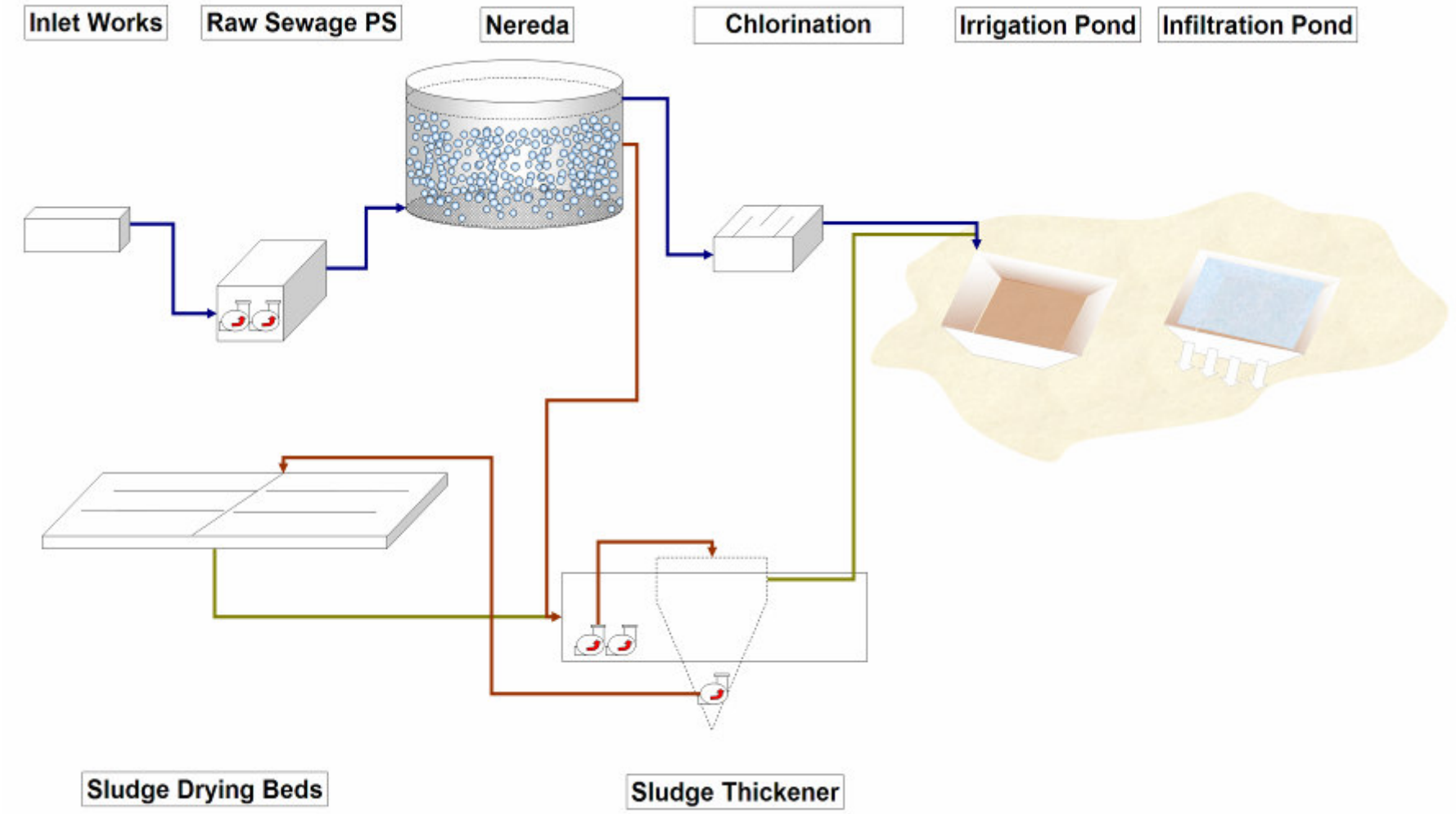


200µm

Gansbaai STP

- Overstrand Municipality, South Africa
- 4 MLD full-scale demo
  - 3x 1,600 m3 Nereda-reactors
- High Portion of Tanker Discharges (concentrated sewage)
- Start-up December 2008
- research partners
  - Technical University of Delft
  - University of Cape Town
  - DHV / SSI

Gansbaai STP



Gansbaai STP

Advanced Water Management Centre

TU Delft

Epe STP

Municipal with significant slaughterhouse wastewater contribution

Continuous pilot runs since 2007 as part of National Nereda Research Program

National Nereda Research Program:

stowa

Waterschap Veluwe

Waterschap Hollandse Delta

Waterschap Rijn en IJssel

Waterschapsbedrijf Limburg

Waterschap Regge en Dinkel

Hoogheemraadschap van Rijnland

Advanced Water Management Centre

TU Delft

DHV

Epe STP

-Replacement exisiting STP by Nereda

- expected start construction: Q2 2010

-Designed for:

- 59,000 p.e. incl. 13,750 from slaughterhouses

	limit	target
N_{tot} – ppm N	< 8	<5
P_{tot} – ppm P	<0.5	<0.3

National Nereda Research Program:

stowa

Waterschap Veluwe

Waterschap Hollandse Delta

Waterschap Rijn en IJssel

Waterschapsbedrijf Limburg

Waterschap Regge en Dinkel

Hoogheemraadschap van Rijnland

Advanced Water Management Centre

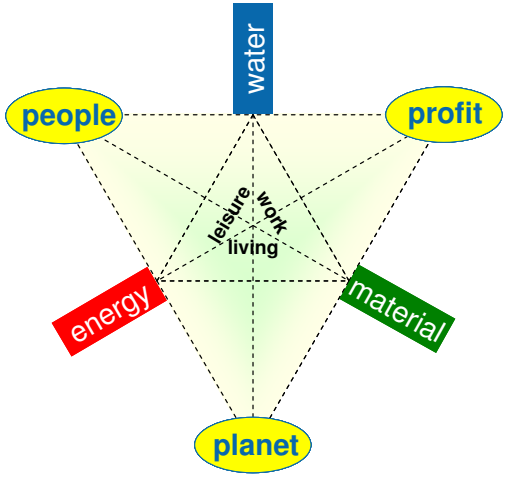
TU Delft

DHV

Pilot test brewery wastewater

- Well known brewery searching for treatment technology with high sustainability
- Existing: UASB + Carrousel®
- Focus on P-reduction:
  - without chemicals: approx. 6 ppm Ptot
  - with chemicals: approx. 1.5 ppm Ptot
- Nereda® pilot test (approx. 9 months)
  - factor 3 higher sludge load
  - achieved performance: < 1-2 Ptot; <5 Ntot (with minimal chemicals: <0.5 Ptot)
  - prevent too much inflow of washed-out UASB-sludge
  - small by-pass as COD-source for full BNR
- Next step: automation stability validation

Improved sustainability



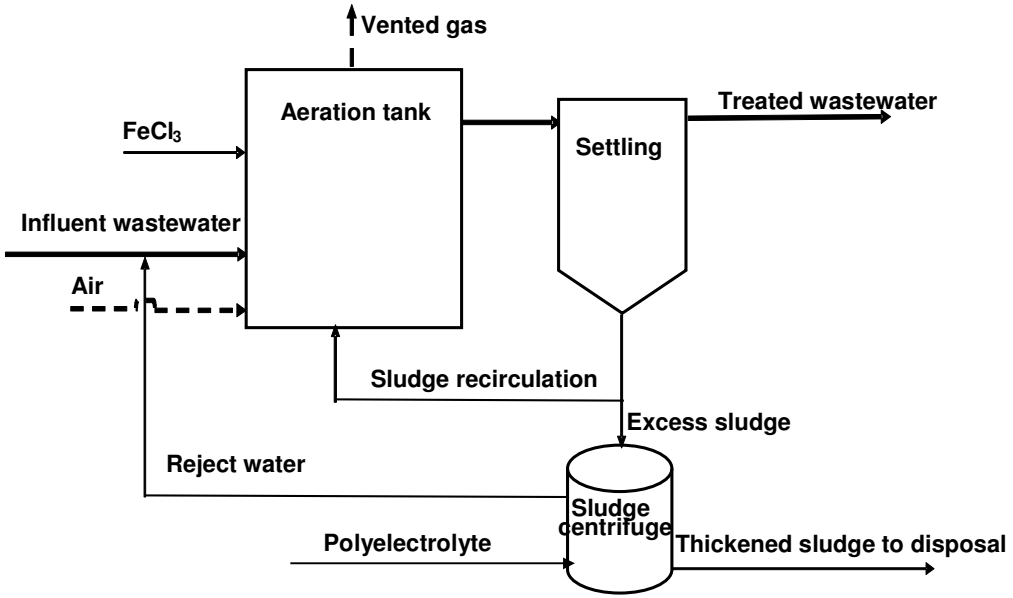
Nereda technology luckily combines cost-effective treatment with a lot of environmental benefits and is a truly sustainable alternative

- Energy reduction → lower depletion of fossil-based energy
- Excellent effluent → reduced aqueous emissions into nature and surface water
- Compact → less construction material
- Cleaner biosludge → lower metal emissions to agriculture
- No or less chemicals → more sustainable / waste reduction

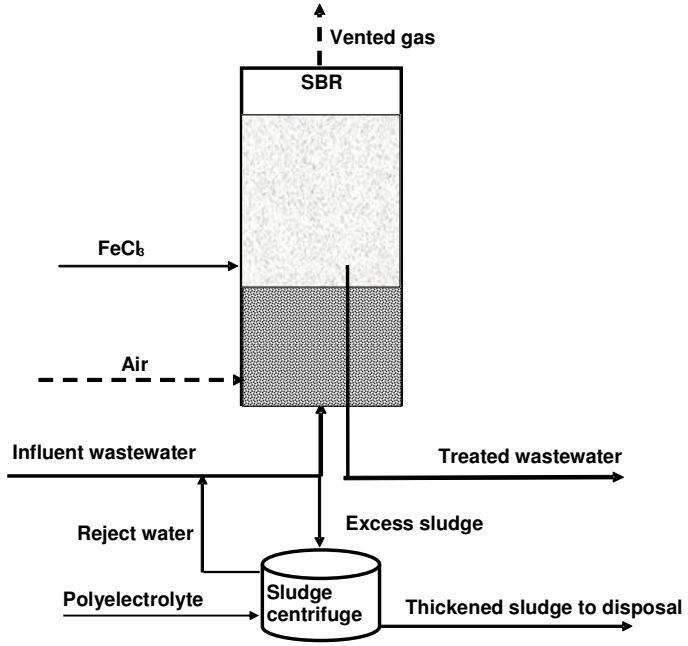
LCA-Assessment Innowatech

- executed by Mats Almemark, IVL (Swedish Environmental Research Institute Ltd)
- Aerobic treatment brewery wastewater after UASB pretreatment
- Similar feed, similar effluent

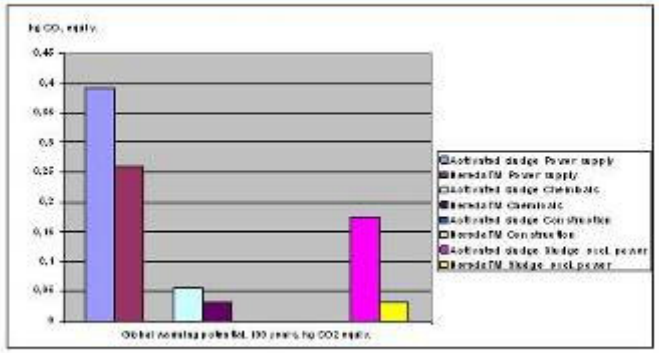
Reference: CAS



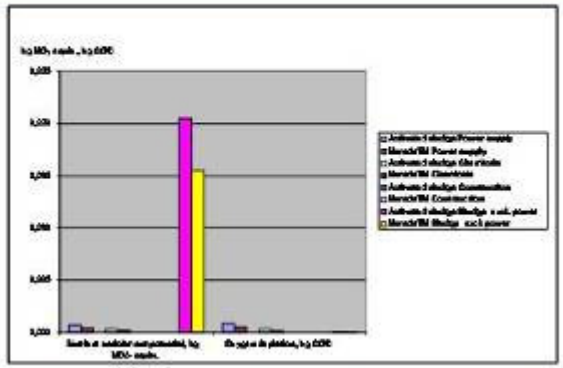
Nereda



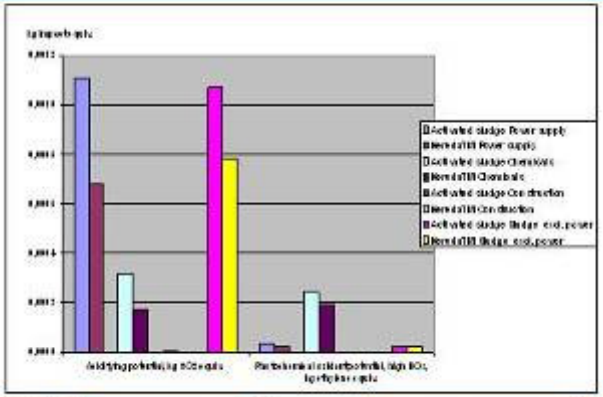
Global warming potential



Nutrient enrichment / oxygen depletion



Acidifying / photochemical potential



Advanced Water Management Centre

TU Delft

DHV

Summary

Nereda is a breakthrough.....

- Simple
- Compact
- Sustainable
- Low investments
- Low operating costs
- Simultaneous biological organic, N and P- removal
- Flexible effluent quality
- Suitable for retrofits

Is a "fresh" technology but.....is already available for serious action:

- First applications are running
- Many others will follow soon
- Will become the new standard

Ingenuity award 2005

Process Innovation award 2006

DOW energy award 2007

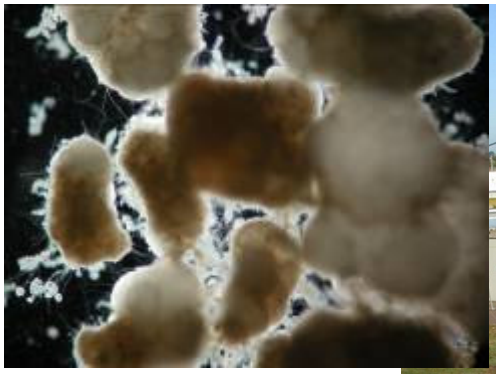
Water Quality & Safety award 2007

Simon Stevin Gezel Award 2007

Runnerup European Business Award for Environment 2008

Technical Excellence Award SAICE 2009

More information?



www.innowatech.org

www.nereda.net

www.DHV.com

www.awmc.uq.edu.au

This presentation has been given within the framework of the EU Innowatech project (Contract No. 036882) that has been financially supported by the EU Commission within the thematic priority Global Change and Ecosystems of the Sixth Framework Program (FP6-2005-Global 4 - SUSTDEV-2005-3.II.3.2)

Advanced Water Management Centre

TU Delft

SIXTH FRAMEWORK PROGRAMME

DHV