Aerobic Granular Sludge

Mark van Loosdrecht – ASPIRE HongKong 2019

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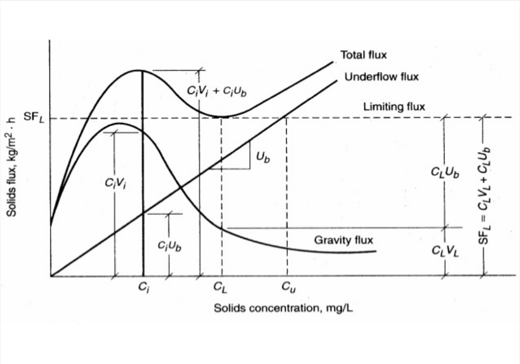
Wastewater Treatment Plants:

Large Area Usage
Complexity Settling
Replace Clarifiers



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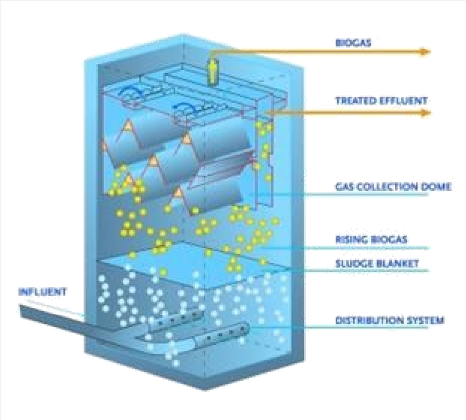
Process Intensification by Efficient Sludge Separation

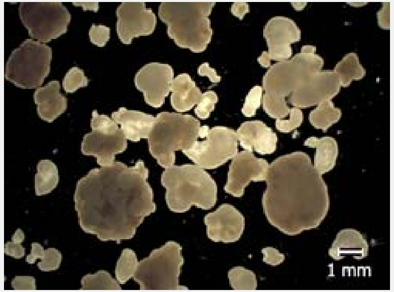


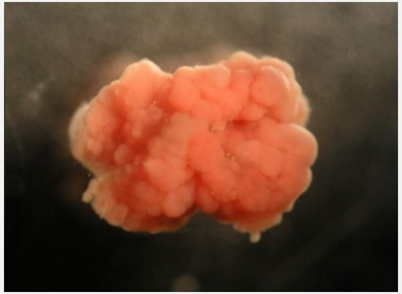
Granular Sludge

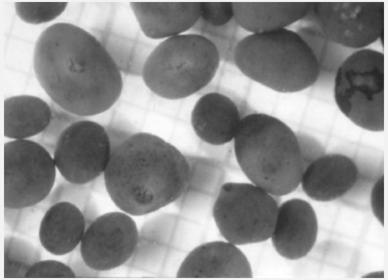
Best of both worlds

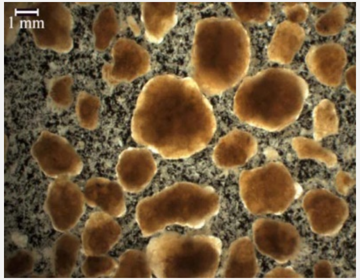
Optimal Biofilm/Flocs Combination

- Easy, gravity driven, separation
- Structuring allows efficient microbial community design
- High mass transfer area
- No clogging









Principle of Granulation

Biology is not needed to understand Granular Sludge formation

Biology is needed to understand the conversion processes in the reactors

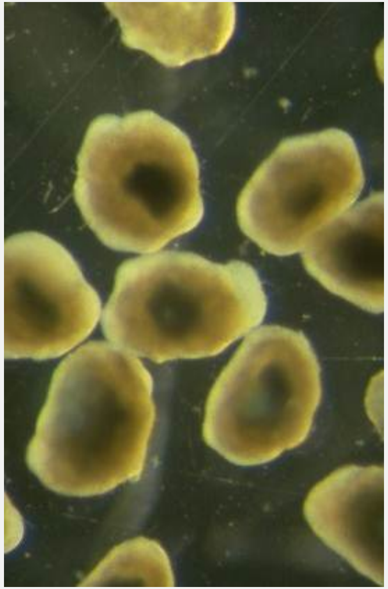
High similarity in morphogenesis of crystals and granules

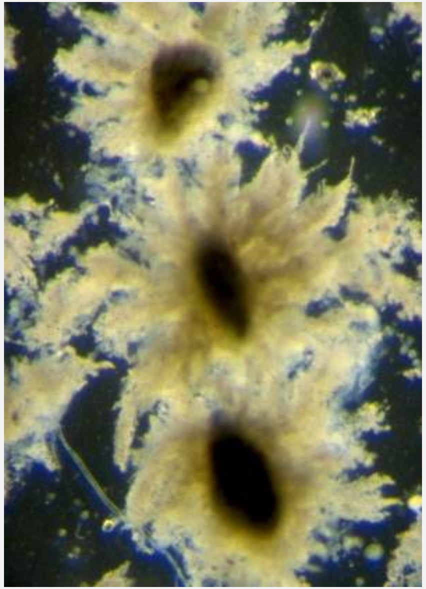
Compact Morphology

→ Slow rates (Methanogens, Anammox)

→ No diffusion limited substrate uptake

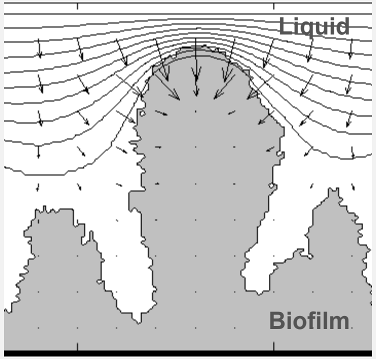
→ Shear can counteract

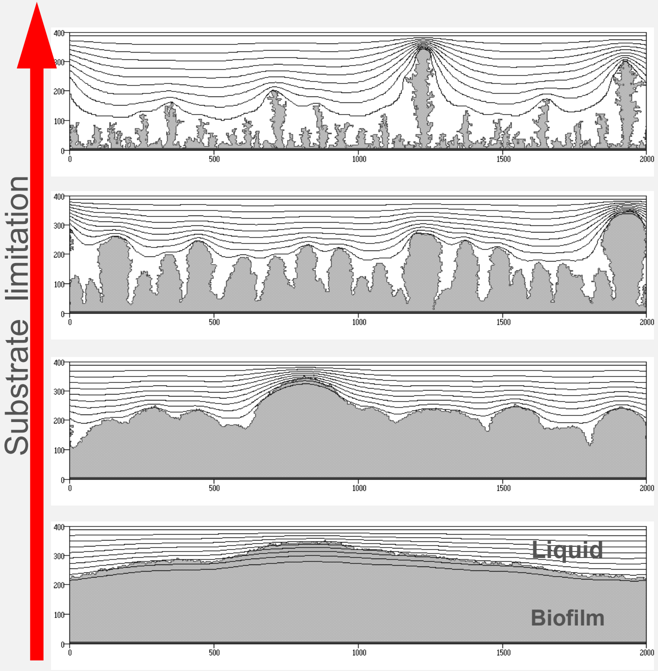




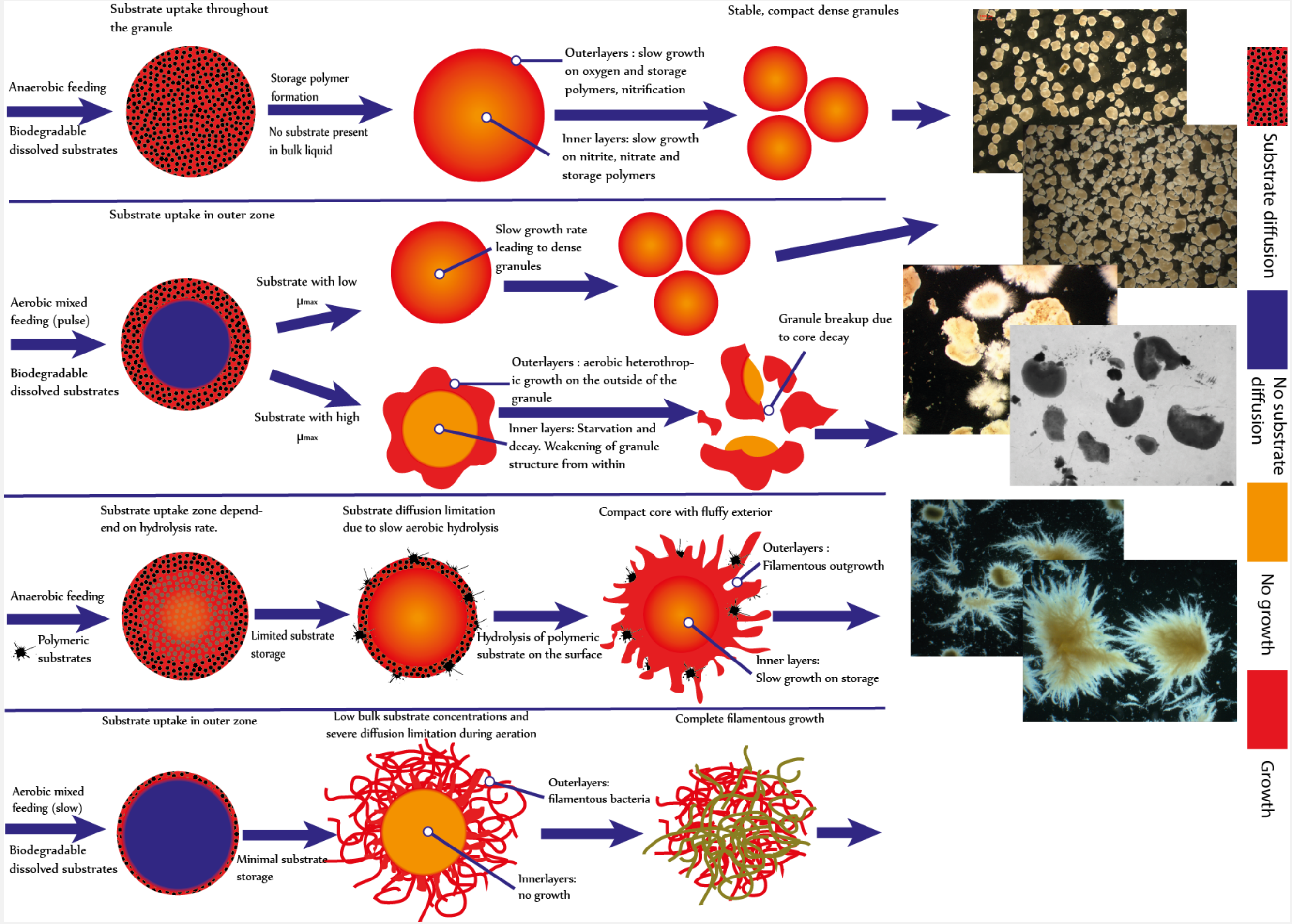
Reaction – Diffusion – Growth Process

Vector field of substrate diffusion flux



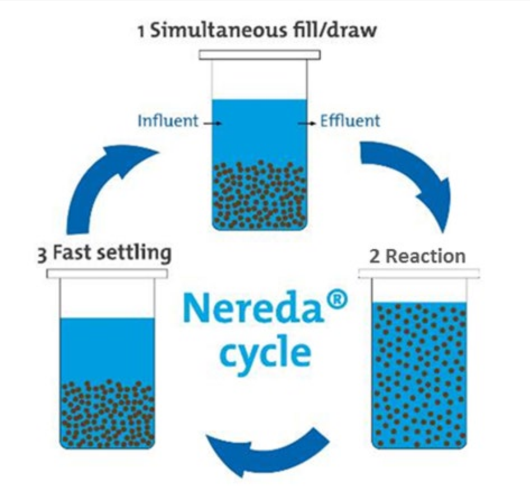


Van Loosdrecht, M. C. M., Heijnen, J. J., Eberl, H., Kreft, J., & Picioreanu, C. (2002). Mathematical modelling of biofilm structures. *Antonie van Leeuwenhoek*, *81*(1-4), 245-256.



Pronk, M., Abbas, B., Al-Zuhairy, S. H. K., Kraan, R., Kleerebezem, R., & Van Loosdrecht, M. C. M. (2015). Effect and behaviour of different substrates in relation to the formation of aerobic granular sludge. *Applied microbiology and biotechnology*, *99*(12), 5257-5268.

Nereda – Aerobic Granular Sludge Technology



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Pronk, M., De Kreuk, M. K., De Bruin, B., Kamminga, P., Kleerebezem, R. V., & Van Loosdrecht, M. C. M. (2015). Full scale performance of the aerobic granular sludge process for sewage treatment. *Water Research*, *84*, 207-217.

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NEREDA versus SBR

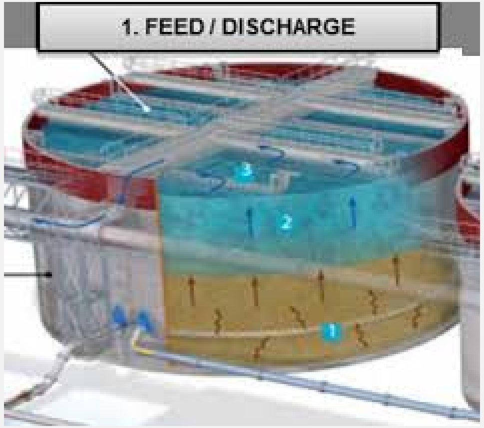
+ Constant influent and effluent to plant
+ Constant volume – no decanters, pump efficiency
+ No idle time or settling time
+ Even oxygen demand versus time in cycle

Important Aspects for Granular Sludge Selection

All readily biodegradable COD removed anaerobically

Separation flocs and granules with short SRT for flocs

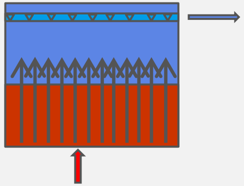
Selective flocculent sludge withdrawal



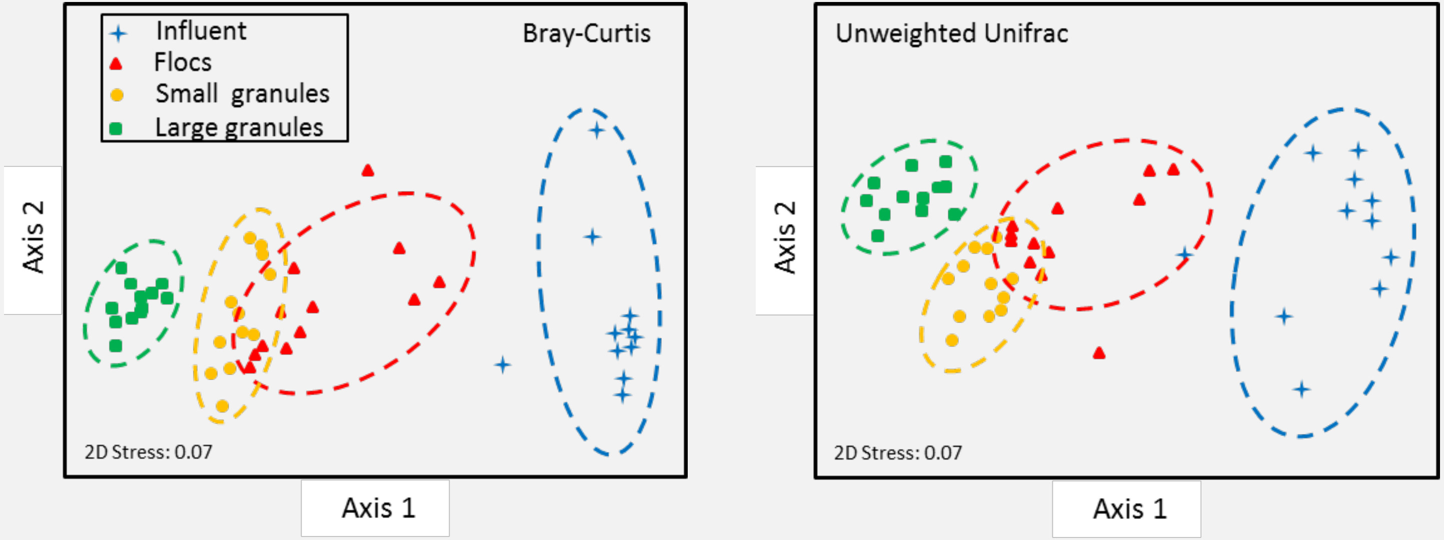
Not:

- Shear
- DO in aeration phase
- Specific biological arguments (EPS/QS etc.)
- Granule instability

➔ Bottom Feed: Self Stabilizing Principle



Microbial Diversity of Different-Sized Aggregates



- Similarity with Influent: Flocs > Small granules > Large granules
- The microbial communities in Flocs were more dynamic than in Granules as can be seen by their wider distribution.

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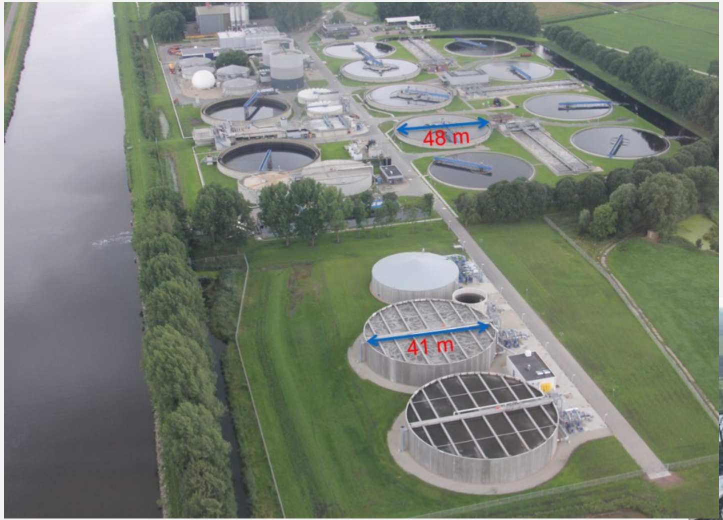
Ali, Muhammad, et al. "Importance of species sorting and immigration on the bacterial assembly of different-sized aggregates in a full-scale aerobic granular sludge plant." *Environmental science & technology* 53.14 (2019): 8291-8301.

Garmerwolde WWTP



50 % of load to Nereda

- Nereda capacity: 140,000 p.e., 20 - 100 MLD (average 30)
- Nereda-reactors: 2 x 9,500 m3
- Ntotal=7 mg/l; Ptotal=1 mg/l

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Pronk, M., De Kreuk, M. K., De Bruin, B., Kamminga, P., Kleerebezem, R. V., & Van Loosdrecht, M. C. M. (2015). Full scale performance of the aerobic granular sludge process for sewage treatment. *Water Research*, *84*, 207-217.

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Nereda Installations World Wide since 2012

https://www.royalhaskoningdhv.com/nereda

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Ringsend WWTP - Ireland

Test cell
94,000 p.e.
21,700 m^3/day

Full plant upgrade
2,400,000 p.e.
159 MGD

NATIONAL NEREDA RESEARCH PROGRAM 2002-2012

stowa

Hoogheemraadschap van Rijnland

WATERSCHAPSBEDRIJF LIMBURG

waterschap Hollandse Delta

Waterschap Veluwe

Waterschap Rijn en IJssel

TU Delft

WATERSCHAP Regge en Dinkel

Nereda® The natural way of treating wastewater

DHV

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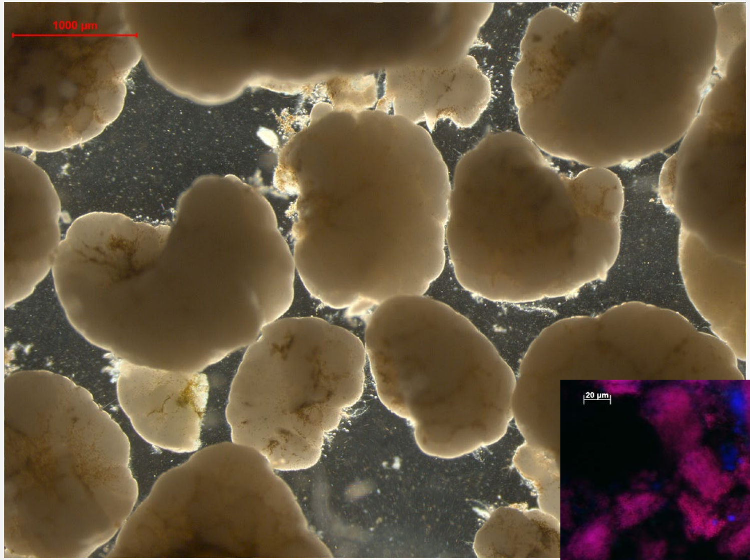
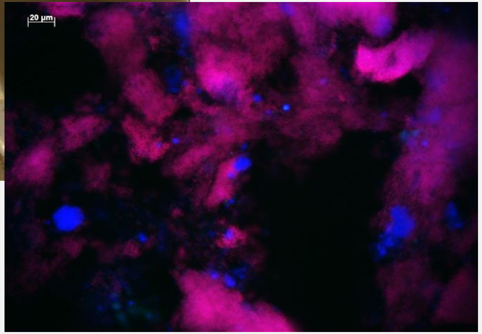
What about seawater/salt?

Seawater Intrusion in Sewers
Seawater Toilet Flushing
Industrial Wastewater

Potential Effects:
- Sulfide Generation
- Osmotic Stress
- Density Variations

Seawater-adapted granules



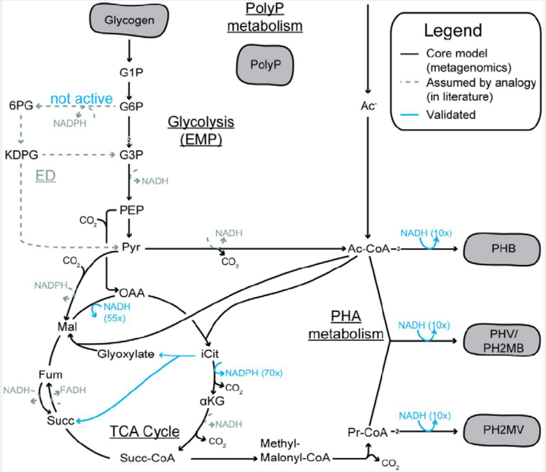


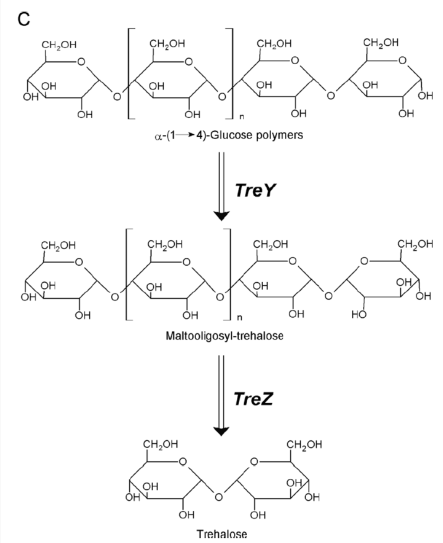
Same PAO Bacteria in
Fresh Water
Saline Water
Seawater

8.00 mg P/g VSS/h for Fresh Water/Seawater
2.90 mg P/g VSS/h for Saline Water (NaCl)

Osmotic Stress - *Accumulibacter* in tidal zones

Watson, S. J., Needoba, J. A., & Peterson, T. D. (2019). Widespread detection of Candidatus Accumulibacter phosphatis, a polyphosphate-accumulating organism, in sediments of the Columbia River estuary. *Environmental microbiology*, *21*(4), 1369-1382.





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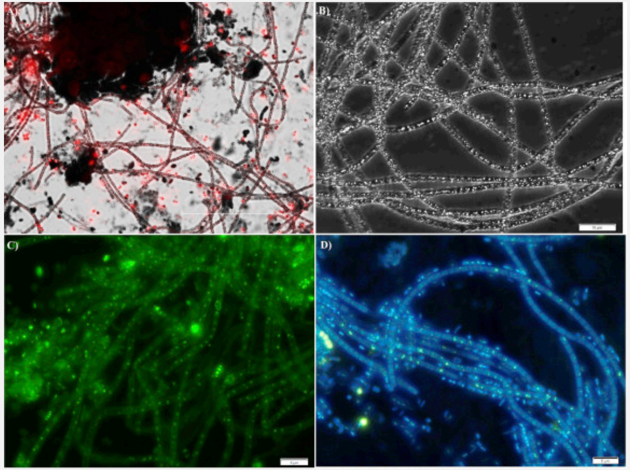
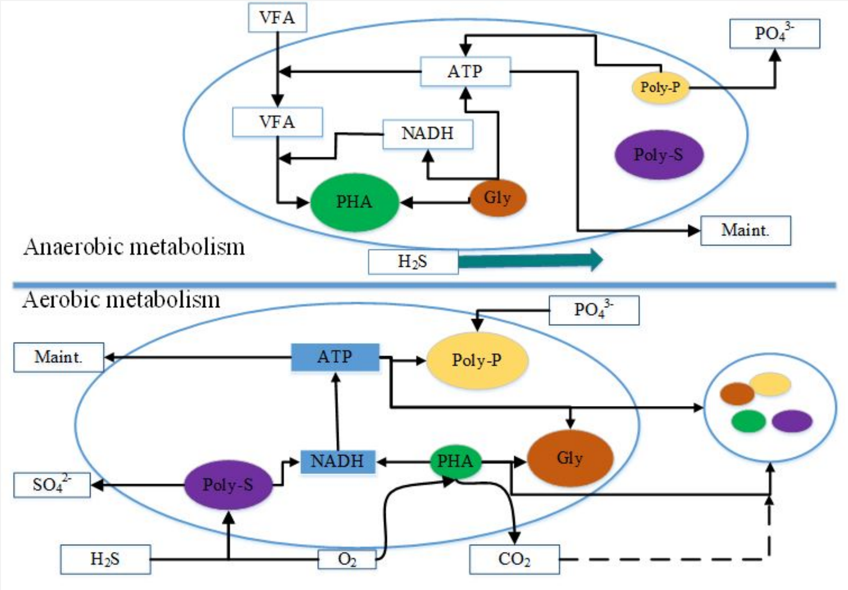
Rapid Change Fresh Water - Seawater

Density Flow

Especially a lab scale problem
Due to low sludge bed height

Sulfide – *Thiotrix caldifontis*



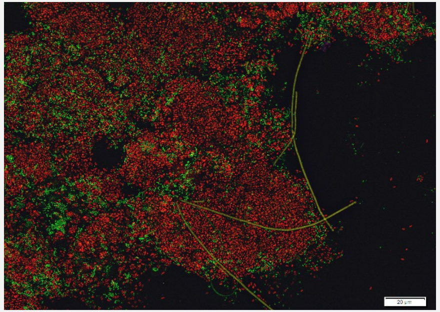


Rubio-Rincón, F. J., et al. "Long-term effects of sulphide on the enhanced biological removal of phosphorus: the symbiotic role of Thiothrix caldifontis." *Water research* 116 (2017): 53-64.

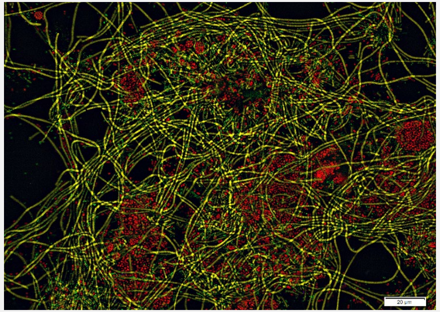
Sulfide – *Thiotrix caldifontis*

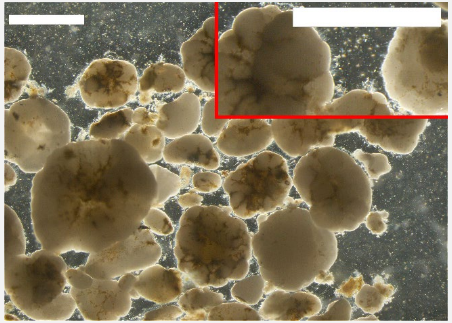
Selection of Filamentous Bacteria - But still good granulation

5 % S-COD Influent



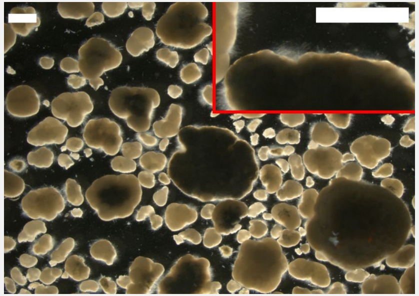
33 % S-COD/L Influent

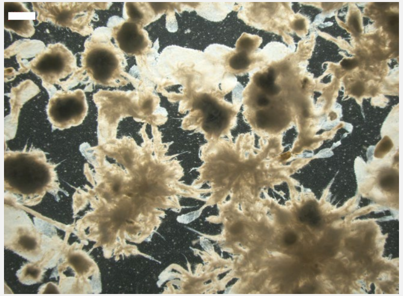




0 % mg S-COD/L Influent

15 % mg S-COD/L Influent





25 % mg S-COD/L Influent

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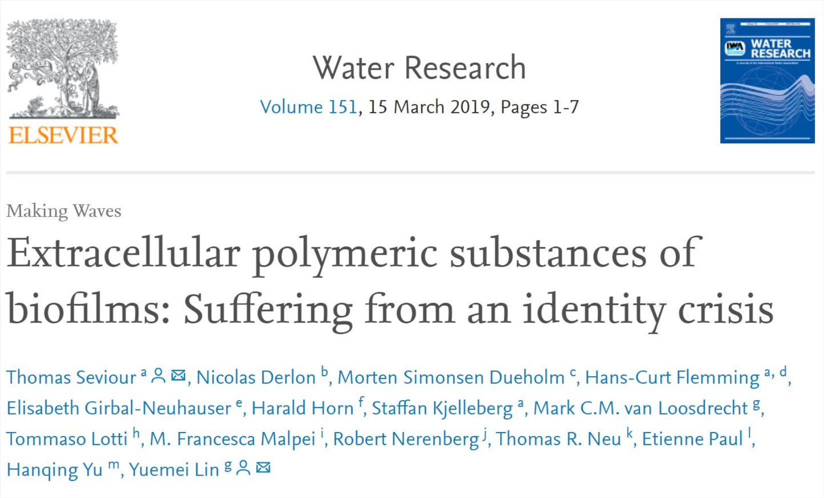
Present - Extracellular Polymeric Substances

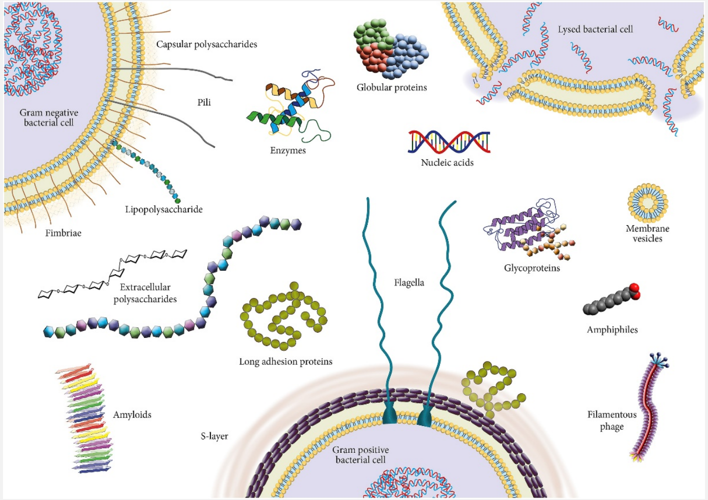
- Structural vs. non-structural polymers


ELSEVIER
Water Research
Volume 151, 15 March 2019, Pages 1-7

Making Waves

Extracellular polymeric substances of biofilms: Suffering from an identity crisis

Thomas Seviour [a], Nicolas Derlon [b], Morten Simonsen Dueholm [c], Hans-Curt Flemming [a, d], Elisabeth Girbal-Neuhauser [e], Harald Horn [f], Staffan Kjelleberg [a], Mark C.M. van Loosdrecht [g], Tommaso Lotti [h], M. Francesca Malpei [i], Robert Nerenberg [j], Thomas R. Neu [k], Etienne Paul [l], Hanqing Yu [m], Yuemei Lin [g]



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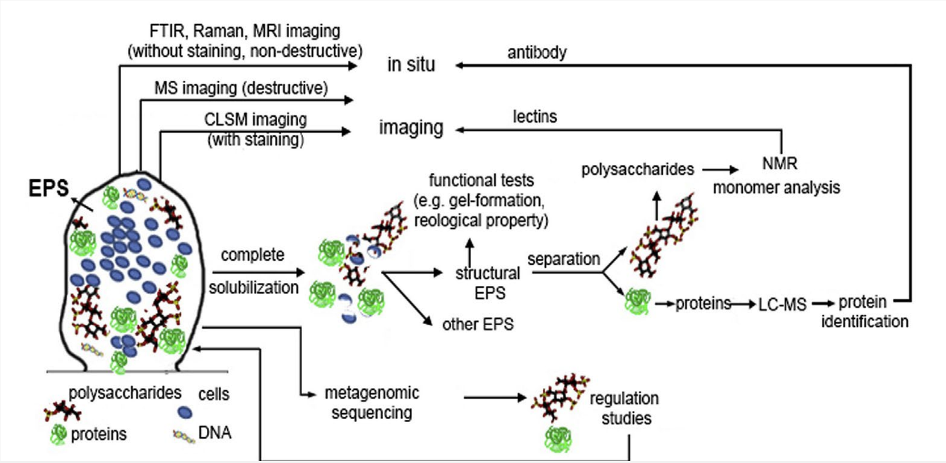
EPS consists of as yet not recognised polymers



Environmental Science & Technology
ACS AuthorChoice
Article
Cite This: Environ. Sci. Technol. 2018, 52, 13127–13135
pubs.acs.org/est

Identification of Glycoproteins Isolated from Extracellular Polymeric Substances of Full-Scale Anammox Granular Sludge

Marissa Boleij,[†] Martin Pabst,[†] Thomas R. Neu,[‡] Mark C. M. van Loosdrecht,[†] and Yuemei Lin[*,†]

Glycosylated amyloid-like proteins in the structural extracellular polymers of aerobic granular sludge enriched with ammonium-oxidizing bacteria

Yuemei Lin[1] | Clara Reino[2] | Julián Carrera[2] | Julio Pérez[1] | Mark C. M. van Loosdrecht[1]

ELSEVIER
Water Research
Volume 155, 15 May 2019, Pages 343-351

Sialic acids in the extracellular polymeric substances of seawater-adapted aerobic granular sludge

Danny R. de Graaff [a], Simon Felz [a], Thomas R. Neu [b], Mario Pronk [a], Mark C.M. van Loosdrecht [a], Yuemei Lin [a]

Evidence of glycoproteins and sulphated proteoglycan-like presence in extracellular polymeric substance from anaerobic granular sludge

Isabelle Bourven, Guillaume Bachellerie, Guy Costa & Gilles Guibaud

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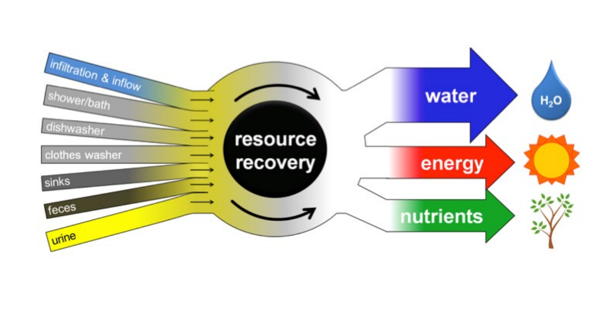
EPS as a resource



- Large fraction of ‘waste sludge’
- Limited oil-based competition
- Biopolymer market supply limited
- Market volume is similar
- Many novel materials possible

- Gel forming EPS from Aerobic Granular Sludge: Kaumera

kaumera
nereda® gum

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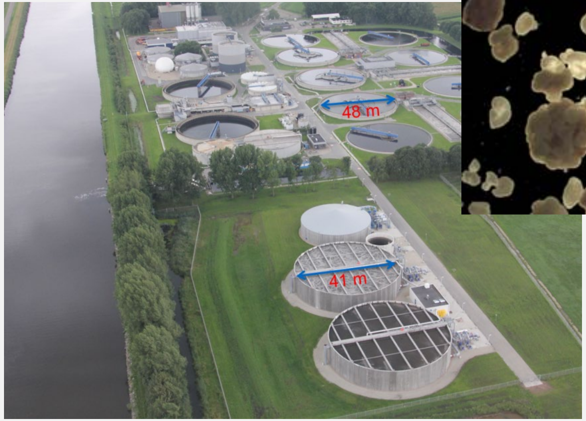
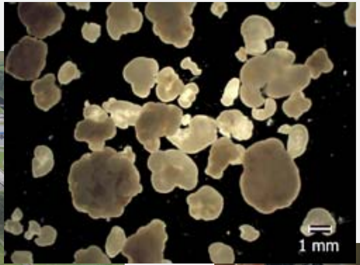
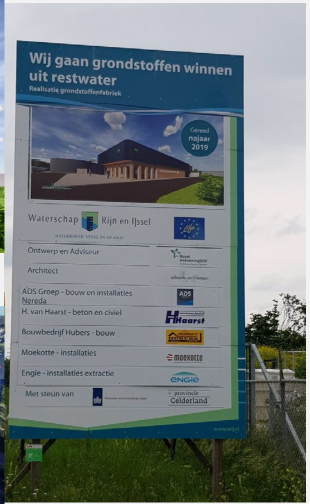
Aerobic Granular Sludge – Nereda – Kaumera







Roughly 70 Nereda WWTP's
Double market volume of Alginates

TU Delft
waterschap vallei en veluwe
stowa
Waterschap Rijn en IJssel
Royal HaskoningDHV
CHAINCRAFT BIOBASED INNOVATORS
npsp sterk in composieten

New Materials based on Kaumera

\+

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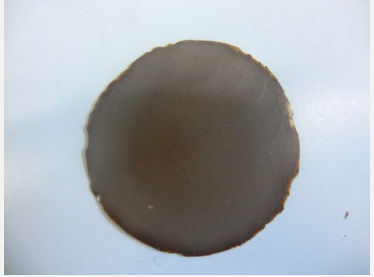
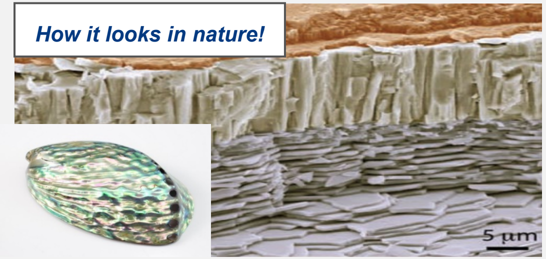
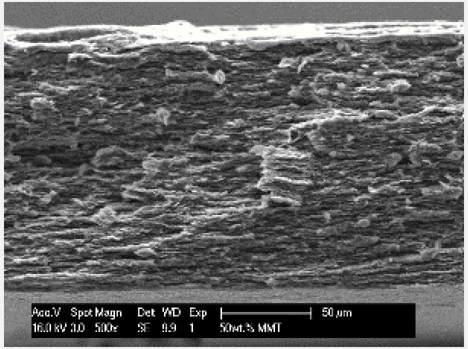




Kaumera

Clay



NGCM

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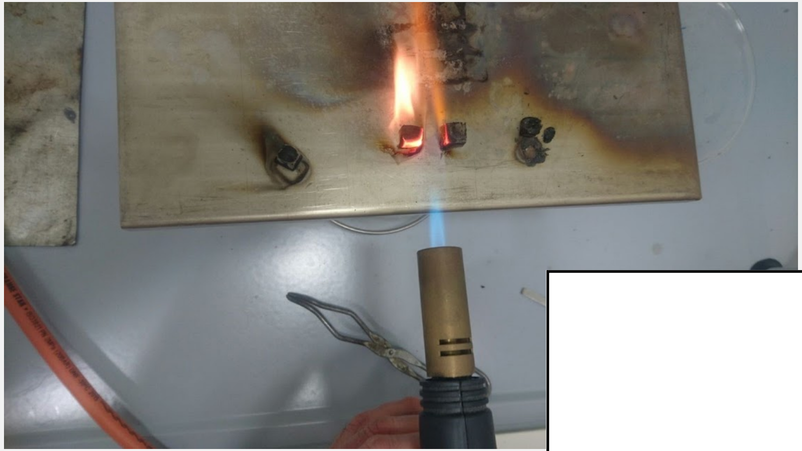
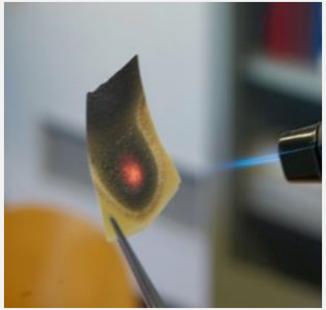
New Materials based on Kaumera





Yuemei Lin

New Materials based on Kaumera

Stiffness comparable to fibre reinforced polyesters

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2GS SLIMY GREEN STUFF

npsp sterk in composieten

Acknowledgements

Mario Pronk
Yuemei Lin
Stephen Picken
Jure Zlopasa

And many MSc and PhD students