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Characterization of sulfate-reducing granular sludge in the SANI® process

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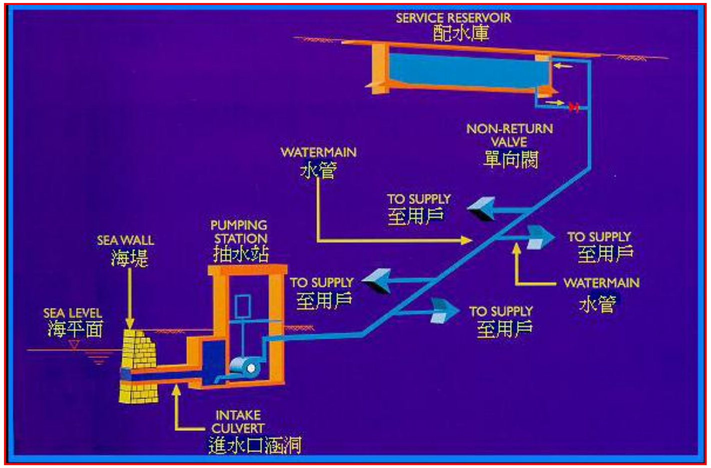
Outline of Presentation

1. Background
2. Characterization of SRB granular sludge aspects:
   - Physical
   - Chemical
   - Biological
3. Conclusions

Background (1):

Hong Kong is one of the most water scarce cities, only **125 m^3/cap/year, far below** International Water Scarcity Standard of **1000**.

In 1958: Seawater toilet flushing was introduced in Hong Kong



Today: 80% of the population enjoys seawater toilet flushing

Seawater toilet flushing saves 750,000 m^3/day of freshwater.

(WSD annual report)

Background (2): Sludge production in Hong Kong

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- Currently about **1,200** tons of dried sludge is generated from wastewater treatment works every day.

Landfill is the only current means for disposal of sewage sludge in Hong Kong (AECOM Asia, 2011)

Landfill capacity will be surpassed by 2018.

Does sludge incineration become the last resort for Hong Kong?

Possible solution: applying SANI process!

Background (3): Description of SANI® Process

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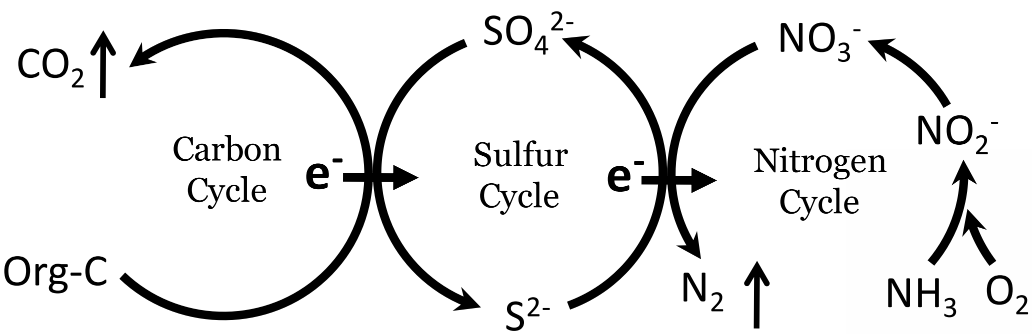
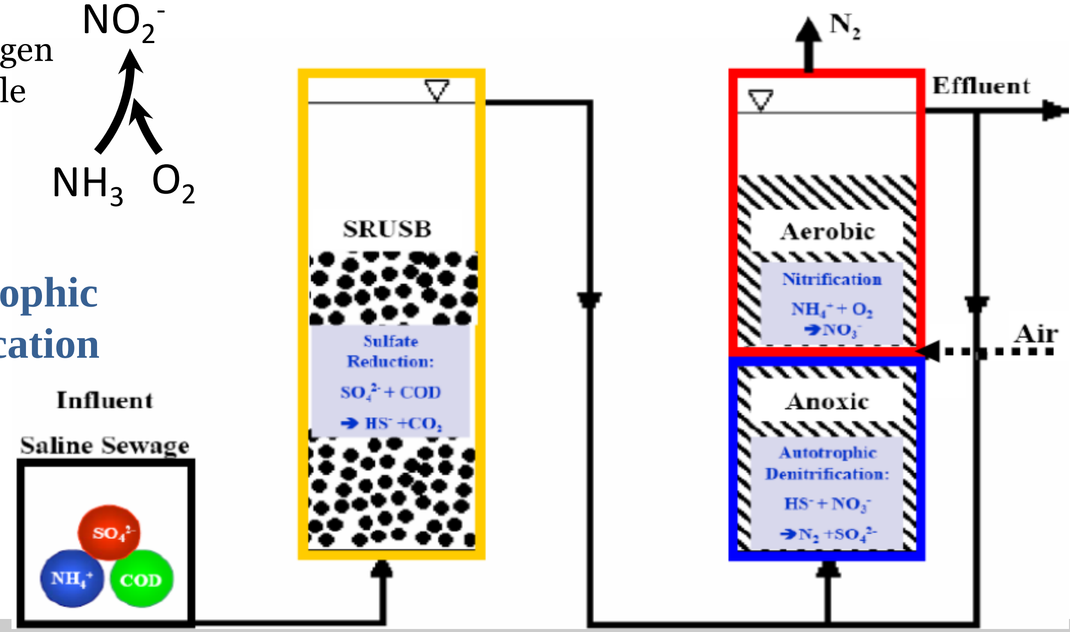
SANI Process:
Sulfate reduction Autotrophic denitrification Nitrification Integrated process



Heterotrophic Sulfate Reduction | **Autotrophic Denitrification** | **Autotrophic Nitrification**



SRUSB: Sulfate Reducing Upflow Sludge Bed

Background (5):
Description of SANI® Process

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Stoich

Biologi

SANI: The

1.78gC

Autotr

CBNR: typ

1.24gN … ge

No **metha** … RUSBs

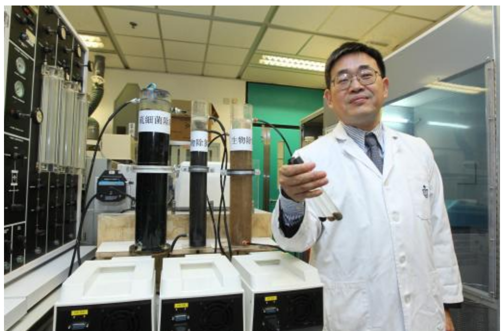
Nitrific

$0.18gNH_4^+$ … $4gH_2O$

(Wang et al

Comparison of SANI process with Conventional Activated Sludge Process	
Save 40% construction cost	***Save 75% space***
Reduce 90% sludge production	***Reduce 35% energy consumption***
Reduce 36% GHG emissions (Lu et al, 2011)	

Background (6):
The milestones of the SANI process



Lab-scale study:
2004-2007
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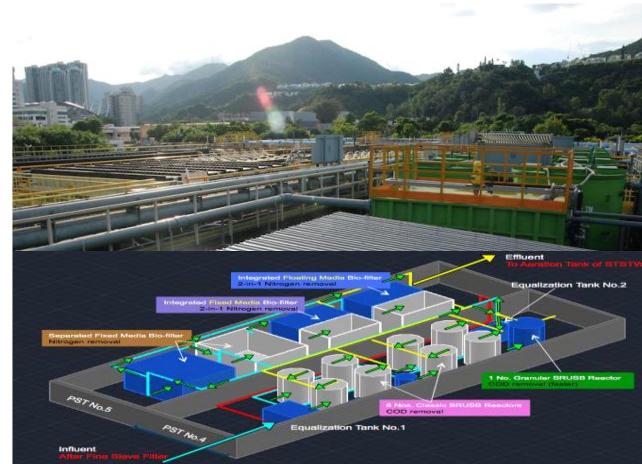


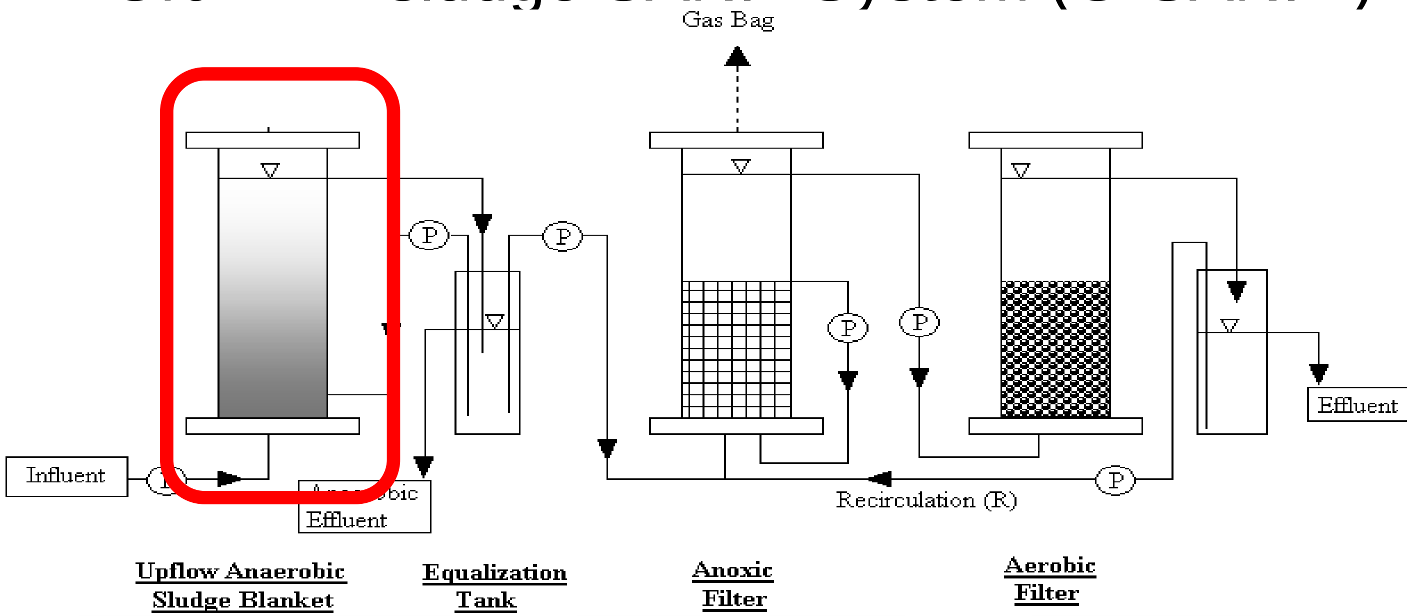
Pilot-scale trial:
2007-2010
Tung Chung
Sewage Pump Station (SPS)

Large-scale demonstration:
2013-2015
Shatin STW

Objective of This Study

Minimize SANI® footprint

Granular sludge SANI® System (G-SANI ®)



Sulfate Reduction

Autotrophic Denitrification

Nitrification

Achieved granulation throughout entire system

Physical Characterization

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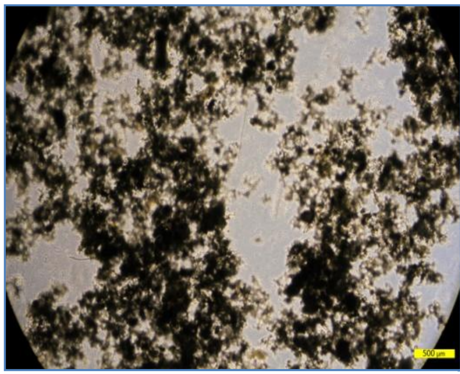
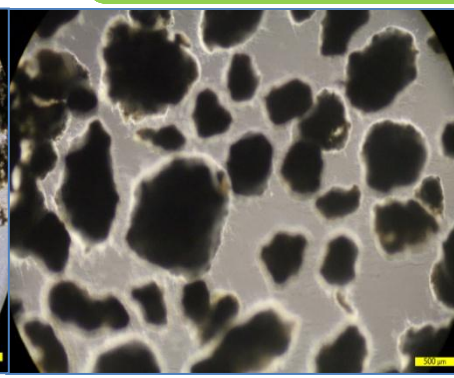
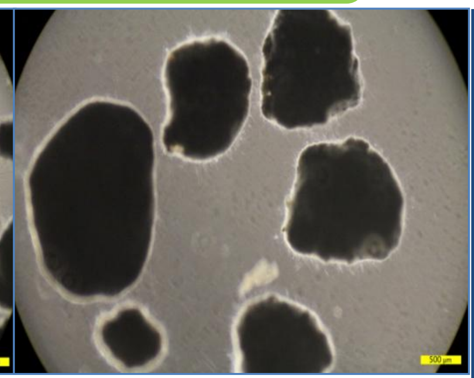
Morphology of granular sludge



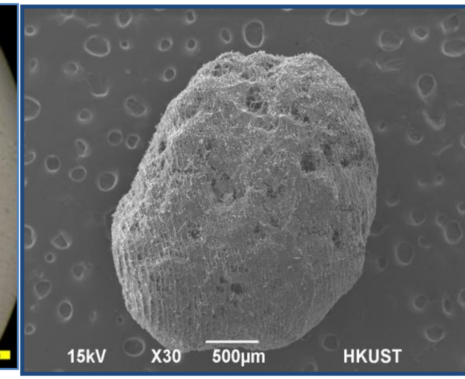
Seeding sludge



60th day

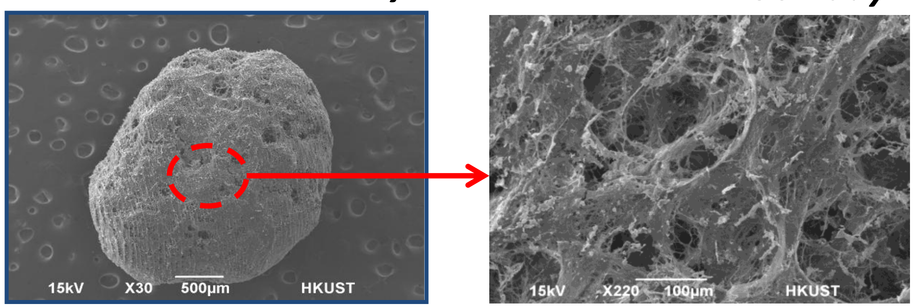


90th day

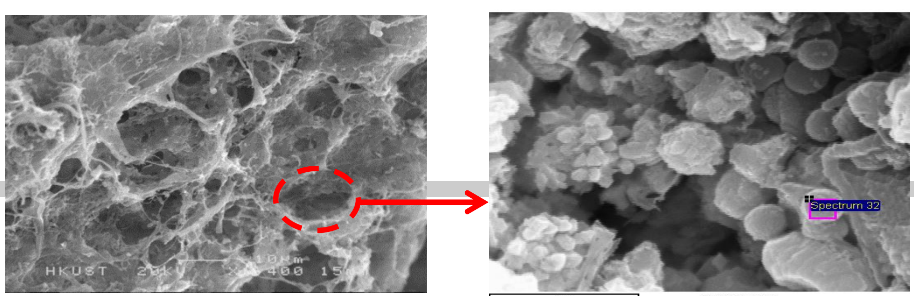


90th day SEM image

Surface



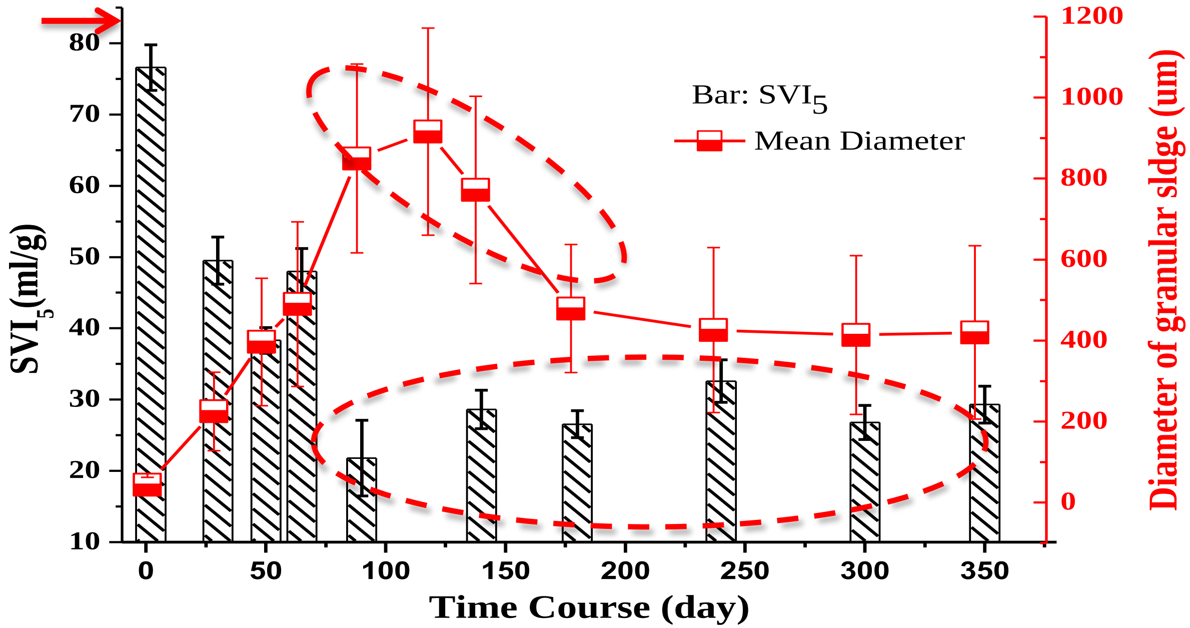
Section



Surface and section of SRB granules look very **porous.**

Physical Characterization

Particle size and SVI_5



SVI_5 maintained at **about 30 ml/g**, VSS/MLSS ratio of 0.72±0.04

The mean granules **diameter** peaked at **916 µm** with SD of 256 after 4 months

Then, decreased to a mean diameter of **420 µm.**

Physical Characterization

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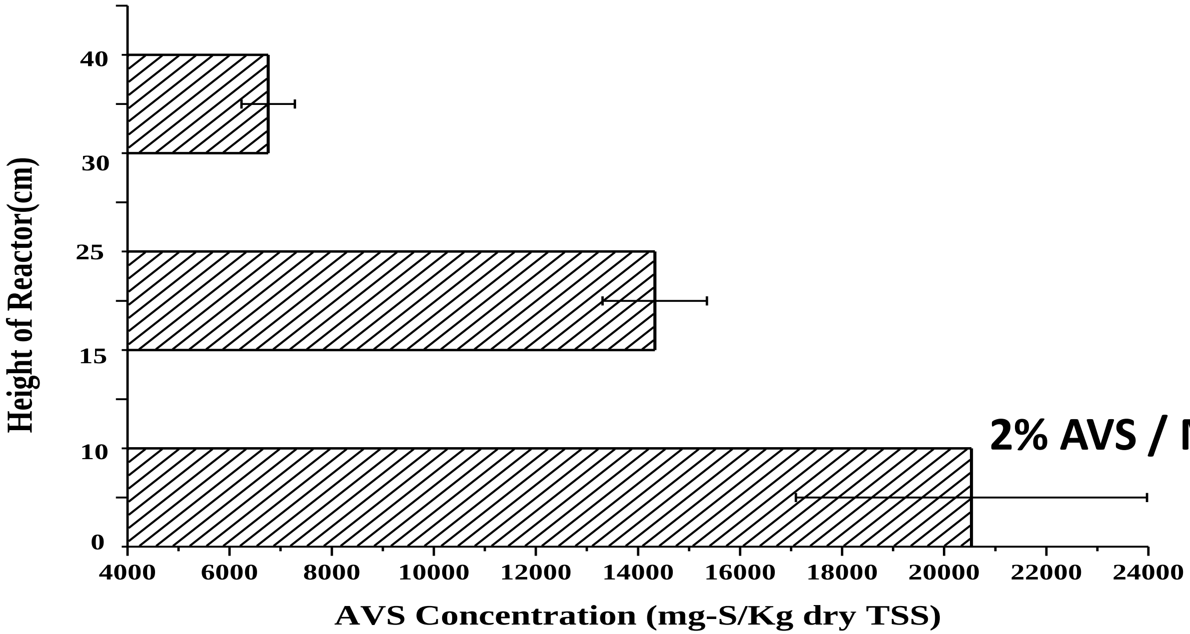
Specific gravity

Anaerobic Granular Sludge Type	Specific Gravity
Starch factory waste-degrading granules	1.041
Alcohol factory waste-degrading granules	1.039
Pentachlorophenol (PCP)-degrading granules	1.020
Municipal wastewater-degrading granules	1.026
Granular methanogenic sludge granules	1.068-1.075
Sulfate Reducing (SRB) granules	**1.068-1.074**

(Alphenaar *et al*., 1994; Wu *et al*., 1993; Fukuzaki *et al*., 1995)

Chemical Characterization

Metal sulfide accumulation: Acid Volatile Sulfide (AVS)

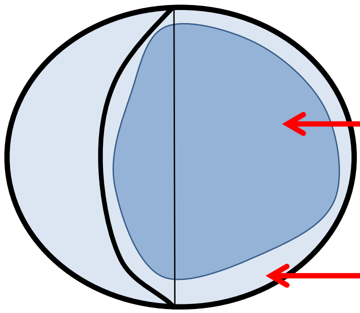


2% AVS / MLSS (dry weight)

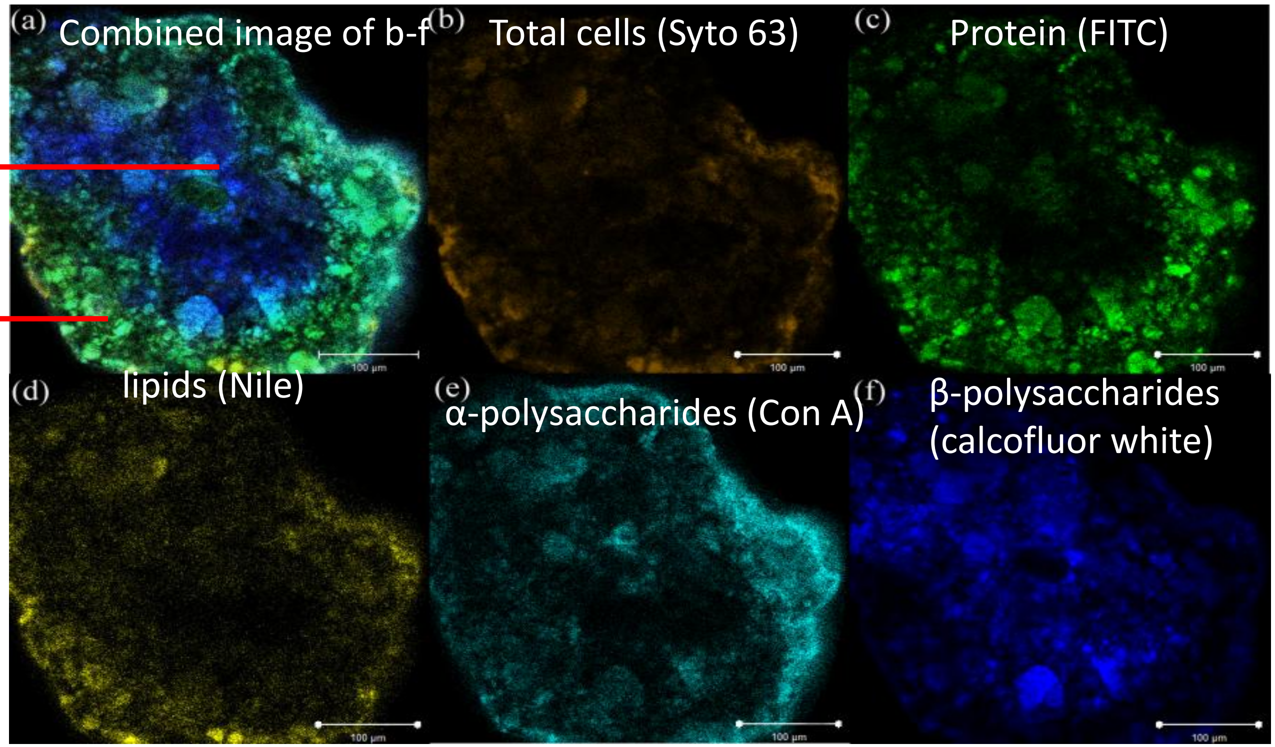
10 times higher than marine sediment (640-2880 mg-S/kg dry TSS) (*Leonard et al., 1993*)
10 times higher than the metal content in digested sludge (0.2%) (*Stylianou et al., 2007*)
An **opportunity** to recover metals from sewage.

Chemical Characterization

Extracellular polymeric substances (EPS) spatial distribution



SRB granules

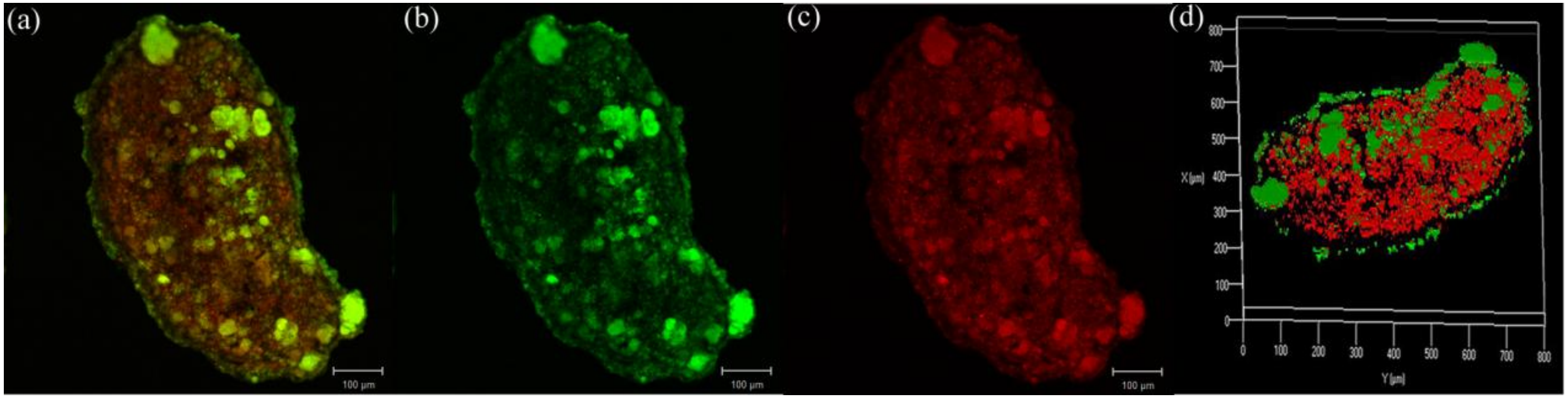


β-polysaccharides at the core of the granules are hydrophilic
Protein and amino acids (outer layer) are more hydrophobic than polysaccharides (*Cuthbertson, 2009; Wang, 2012*)

High hydrophobicity surface, and a hydrophilic internal structure.

Biological Characterization

SRB spatial distribution



Combined image of b and c | **Green: total bacteria** | **Red: SRB** | 3-D distribution of SRB amongst total bacteria

High SRB intensity throughout the granule sections;
Thin outer shell mainly consisting of non-SRB

Distribution pattern suggests a possible collaboration niche between SRB and other bacteria.

Biological Characterization

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Microbial community

Genus	Relative abundance of the sequences (%)		
	Inoculums	90 day	358 day
Desulfobulbus	0.49%	18.1%	42.1%
Desulfobacter	0%	13.6%	1%
Desulfomicrobium	0.35%	5.6%	0%
Desulfosarcina	0%	0.73%	0.45%
Desulfovibrio	0%	0.6%	0%
Desulfobacterium	0%	0.1%	0%
Methylocystis	2%	0%	0%
Trichococcus	0%	12.5%	12%
Prosthecochloris	0%	0%	19%

Cluster distance	Seeding sludge	90-d granules	358-d granules
0.03	Coverage 90%	Coverage 94%	Coverage 95%

SRB	Abundance (%)	Genera
Inoculum	0.84	2
90–day	38.6	6
358–day	44	3

Prosthecochloris: oxidize sulfide to sulfur globules (*Kumar et al., 2009*)

Conclusions

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- SRB granular reactor can achieve organic loading rate of **11 kg COD/m^3-day** with **40 min HRT** and 90% COD removal.
- Diameter of the granules was **approximately 450 μm with SVI$_5$ ~ 30 ml/g, specific gravity 1.069-1.074.**
- SANI process offers an **opportunity** to **recover metals** from sewage.
- The distribution patterns of proteins and polysaccharides assist the SRB granules in building a **stable and firm external structure** and **an internal hydrophilic environment**.
- SRB spatial distribution pattern suggests a possible **collaboration niche** between SRB and other bacteria.