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Internal vs. external carbon sources for enhancing denitrification in activated sludge systems

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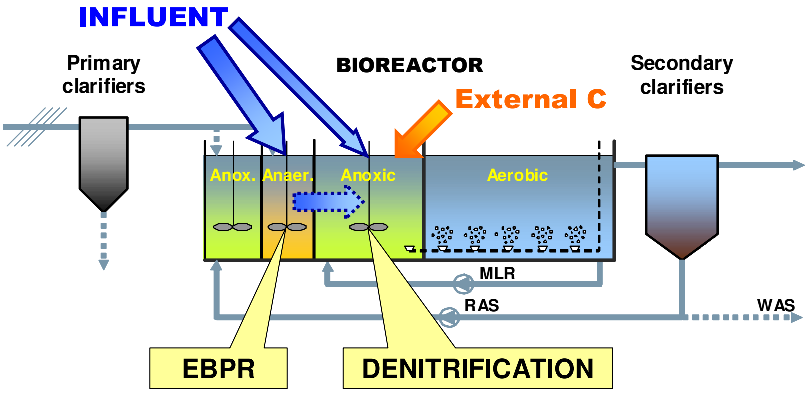
Outline of the presentation

- Introduction
- Types of carbon sources in WWTPs
- Aim and scope of the study
- Examples and summary of the results
- Conclusions

Introduction (1)

- Efficiency of denitrification and EBPR in BNR systems is strongly dependent on the availability of appropriate carbon sources
- Supply of organic substrates in municipal wastewater, required for both denitrification and EBPR, is normally limited

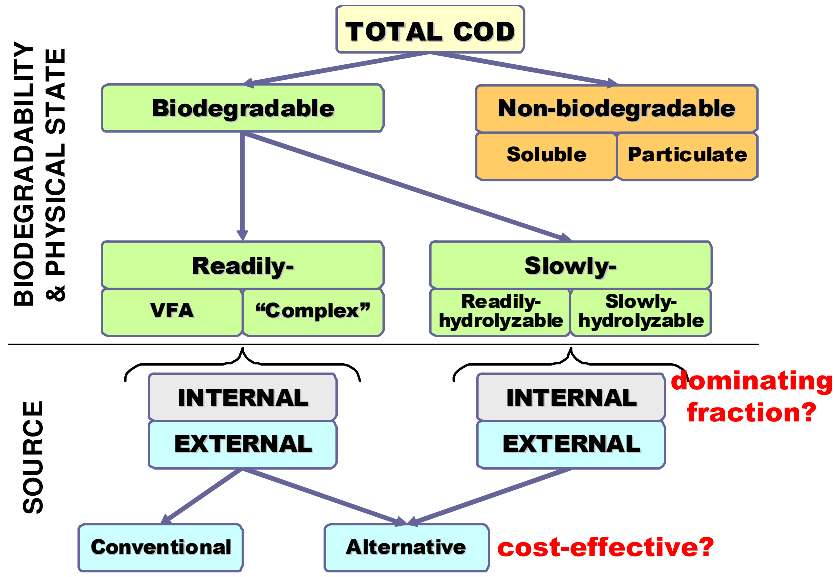
Substrate demand in BNR systems



Introduction (2)

- Efficiency of denitrification and EBPR in BNR systems is strongly dependent on the availability of appropriate carbon sources
- Supply of organic substrates in municipal wastewater, required for both denitrification and EBPR, is normally limited
- **Effects of readily biodegradable (internal and "conventional" external) carbon sources have extensively been investigated and reported**
- **Little is known about the influence of slowly biodegradable (internal) and "alternative" external carbon sources.**

Classification of organic compounds



External carbon sources

- Conventional („commercial”)
  - Methanol
  - Ethanol
  - Acetic acid or sodium acetate (effect on EBPR!!!)
  - Glucose
- Alternative (industrial wastewater, by-products and waste materials) – **in many cases, the problem of high costs of commercial organic compounds can be overcome if “***by chance one does have access to industrial wastewater, for example, brewery wastewater*” **(Henze et al., 1995)**

Characteristics of alternative C sources

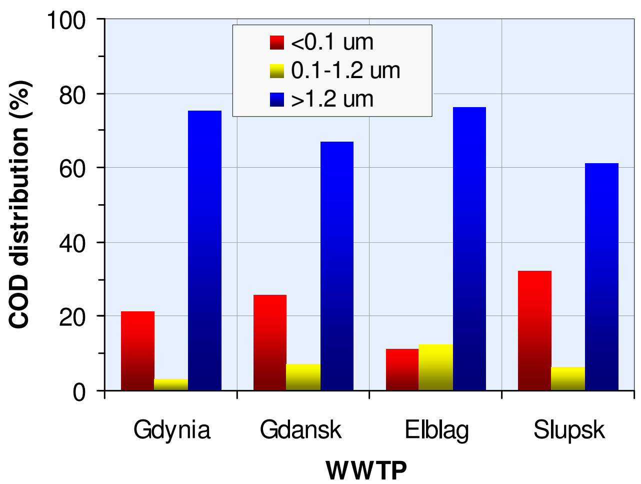
- Utilization of industry-originated wastes or by-products as a carbon source for denitrification - for over 20 years
- The „alternative” carbon sources should be (WEF, 2005):
  - „**Clean**” (i.e. free of metals and other contaminants),
  - **Stable** in terms of the composition and content of readily biodegradable organic compounds,
  - **Available** in the required quantity on a consistent schedule.
- Food industry effluents appear to be good candidates for the external carbon source due to:
  - High C/N ratios,
  - High content of readily biodegradable organic fraction.
- Potential operating problem includes a variation in quality and quantity resulting from the production cycles.

NURs with different C sources - examples

Carbon source	NUR, mg N/(kg VSS·h)	Reference
INTERNAL*		
- readily biodegradable	**3.3 – 5.7**	Naidoo et al. (1998)
- slowly biodegradable	**1.6 – 3.6**	Naidoo et al. (1998)
EXTERNAL (CONVENTIONAL)		
- methanol (acclimated biomass)	**3.0 – 4.5**	Christensson et al., 1994; Nyberg et al., 1996; Purtschert et al., 1996; Fillos et al., 2007
EXTERNAL (ALTERNATIVE)		
- winery wastes	**2.0**	Rodriguez et al. (2007)
- potato processing	**4.1**	Rodriguez et al. (2007)
- ice cream production	**2.7**	Cappai et al. (2004)
- beet-sugar processing	**3.3**	Cappai et al. (2004)

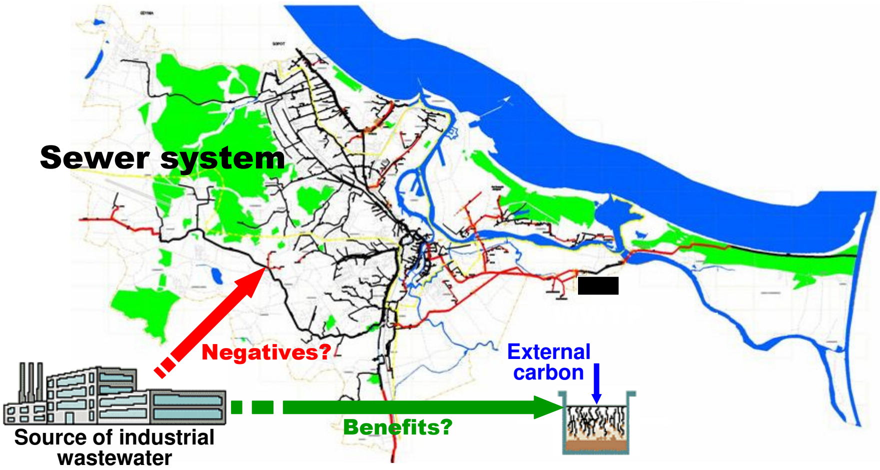
* - based on the results of measurements in 8 large European WWTPs

Physical characteristics of wastewater



Over 65% organic compounds occur in colloidal and particulate form !!!

Potential role of industrial wastewater



Aim and scope of the study (1)

Determine the immediate effects of dosing different carbon sources on the denitrification capability and EBPR interactions of a full-scale process biomass

Batch tests with different carbon sources

- **Internal** (wastewater with/without pretreatment)
- **External conventional** (acetic acid, ethanol)
- **External alternative** (distillery by-products)

Aim and scope of the study (2)

Determine the immediate effects of dosing different carbon sources on the denitrification capability and EBPR interactions of a full-scale process biomass

Batch tests with different carbon sources

- Conventional NUR measurements
- NUR measurements during anoxic P uptake
- Conventional OUR measurements

Aim and scope of the study (3)

Determine the effects of different carbon sources (internal vs. external) on the denitrification capability and EBPR interactions of a full-scale process biomass

STEP 1 — **Batch tests with different carbon sources**

- Conventional NUR measurements
- NUR measurements during anoxic P uptake
- Conventional OUR measurements

STEP 2 — **Adaptation of biomass to exteranal C source**

STEP 3 — **Modeling hydrolysis and external carbon addition**

Location of the studied plant

Gdansk WWTP (570,000 PE)

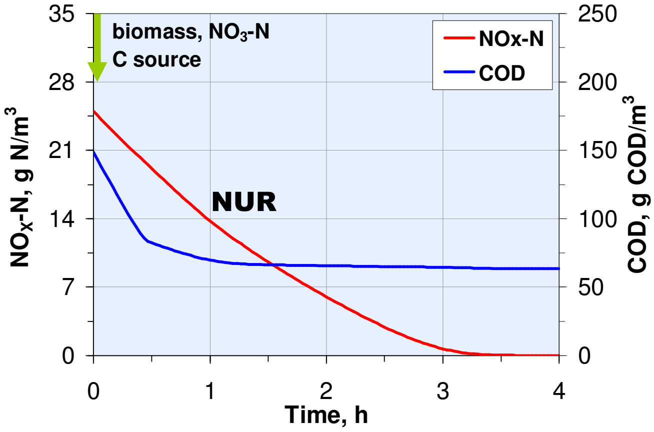
Characteristics of the studied plant

Parameter	Unit	Monthly averages (2006 – 2009)
Operating parameters:		
Influent flow rate	m³/d	75,800 – 98,400
	MGD	20.1 – 25.3
Process temperature	ºC	11.8 – 21.7
Sludge Retention Time	d	17 – 25
Hydraulic Retention Time	d	0.9 – 1.3
Concentrations in primary effluent:		
COD	gCOD/m³	540 – 930
Total N	gN/m³	70 – 97
Total P	gP/m³	11.5 – 19.2
Concentrations in secondary effluent:		
COD	gCOD/m³	36 – 67
Total N	gN/m³	9.3 – 12.8
Total P	gP/m³	0.4 – 1.1

Measurements in batch tests (1)

I type:

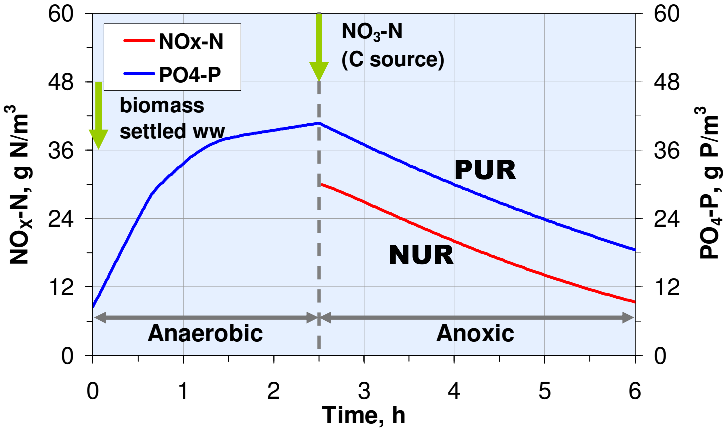
Conventional NUR measurements



Measurements in batch tests (2)

II type:

NUR measurements during anoxic P uptake

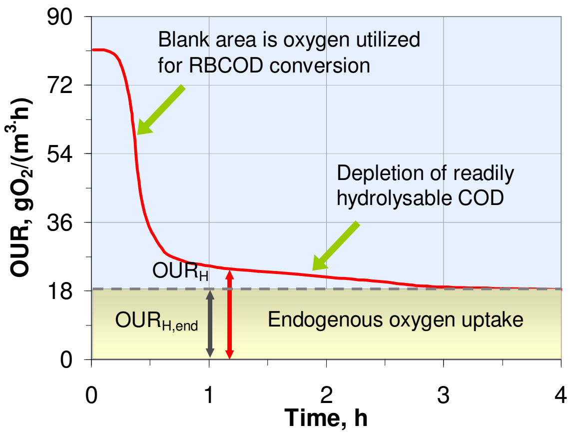


Measurements in batch tests (3)

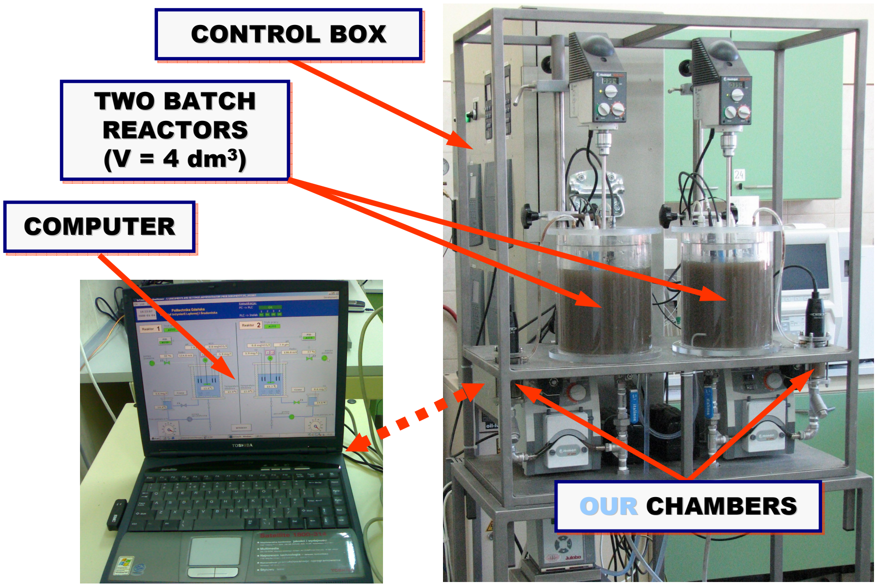
III type:

Conventional OUR measurements

$$Y_H = \frac{COD_{degraded} - \int_0^t OUR(t)dt}{COD_{degraded}}$$



Laboratory set-up

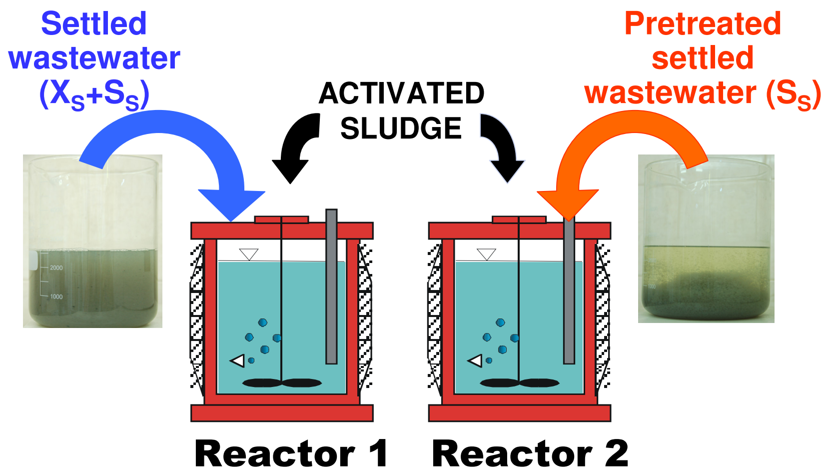


Examined carbon sources

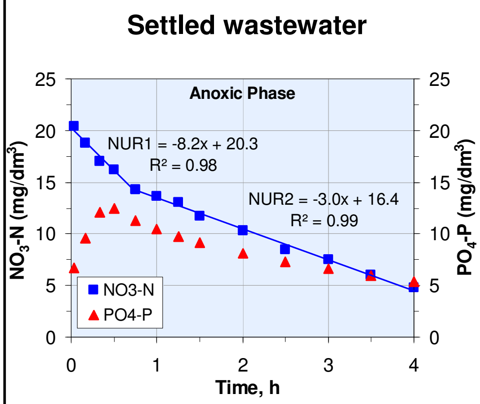
Parameter	Unit	Settled wastewater	Acetic acid
COD	g COD/m³	633 ± 168	913,000
COD soluble	g COD/m³	206 ± 65	913,000
TN	g N/m³	77 ± 9	-
TP	g P/m³	18 ± 2	-
TSS	g/m³	286 ± 68	-

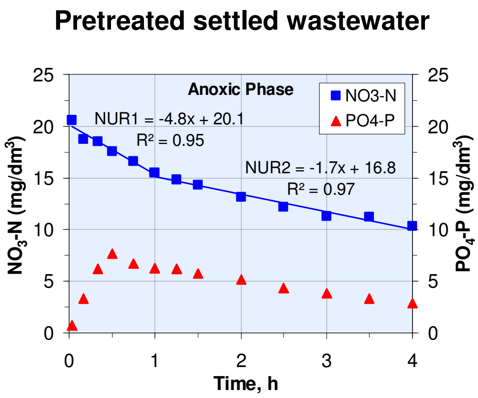
Parameter	Unit	Ethanol	Distilled raw alcohol	Fusel oil
COD	g COD/m³	1,598,000	2,143,000	1,989,000
COD soluble	g COD/m³	1,598,000	1,210,000	1,809,000
TN	g N/m³	-	500	0.3
TP	g P/m³	-	0.6	0.2
TSS	g/m³	-	13	69

Batch test procedure with the settled wastewater

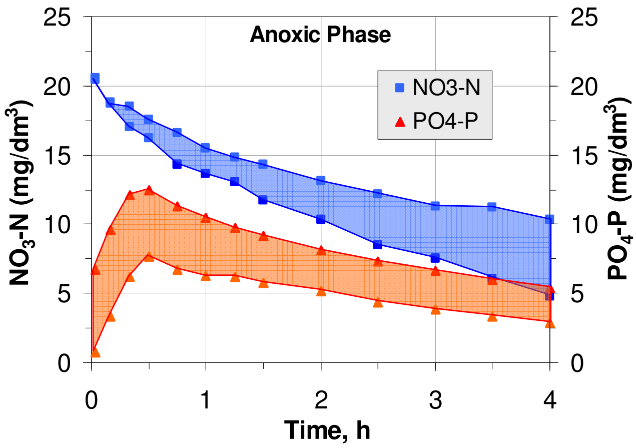


Conventional NUR measurements (1)

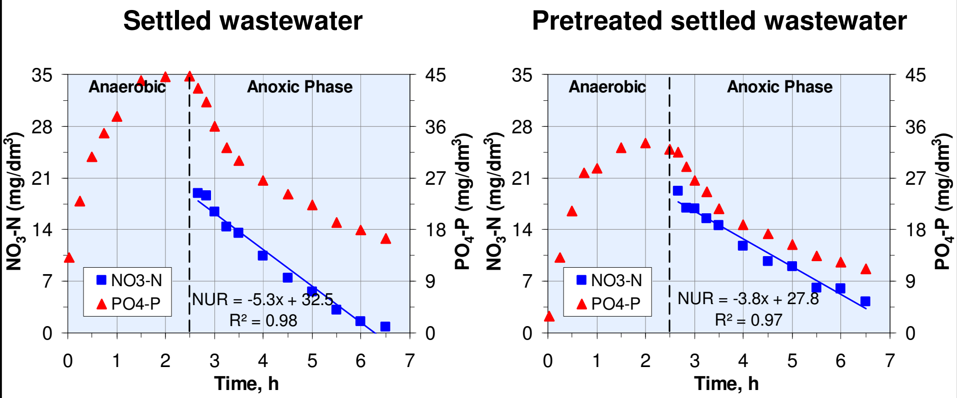




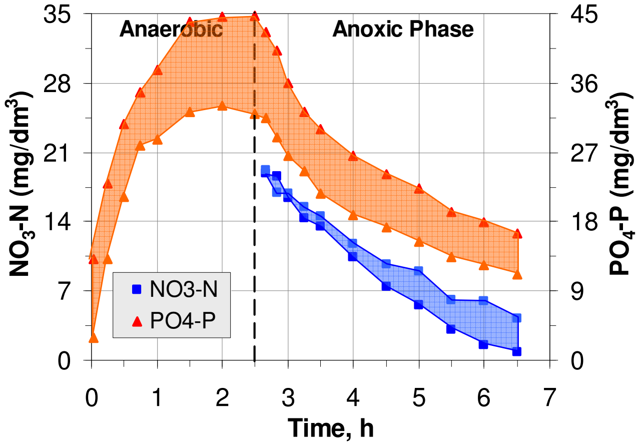
Conventional NUR measurements (2)



NUR measurements during P uptake (1)



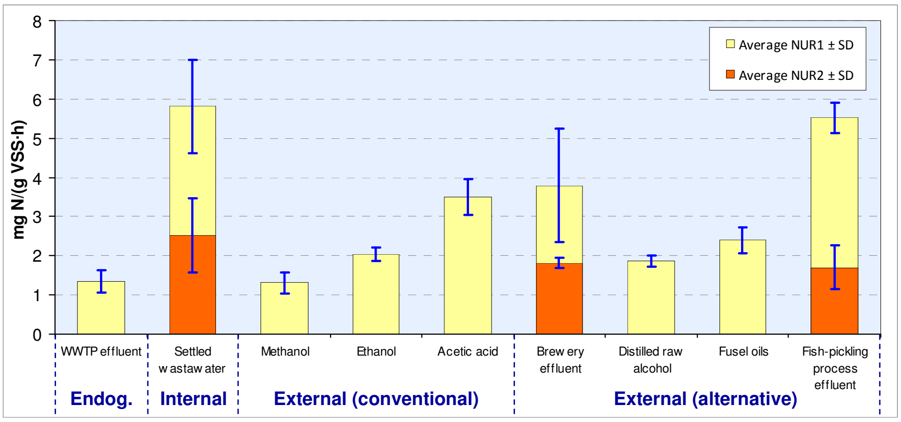
NUR measurements during P uptake (2)



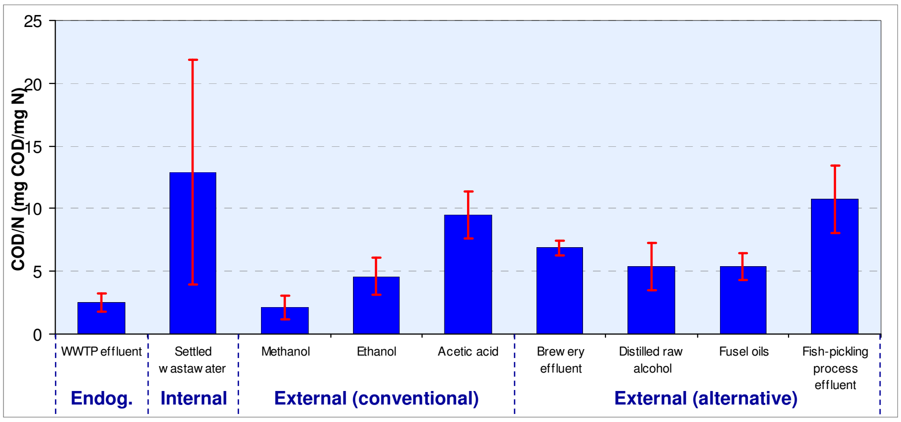
Summary of the results with settled wastewater (with and without pretreatment)

Process rate	Unit	Settled wastewater	Pretreated settled wastewater	Average reduction
"Conventional" denitrification test				
NUR1	mg N/(gVSS·h)	3.7 – 5.5	2.6 – 4.2	**24%**
NUR2		1.3 – 2.0	1.0 – 1.6	**14%**
PRR & anoxic/aerobic PUR test				
PRR	mg P/(gVSS·h)	7.8 – 13.0	3.9 – 11.6	**14%**
PUR_{Anoxic}	mg P/(gVSS·h)	3.4 – 6.6	1.2 – 6.0	**46%**
NUR	mg N/(gVSS·h)	1.6 – 2.7	0.7 – 2.7	**26%**
$PUR_{Aerobic}$	mg P/(gVSS·h)	5.3 – 13.8	2.1 – 12.6	**34%**
OUR_{Max}	mgO_2/(gVSS·h)	22.0 – 33.4	18.2 – 31.0	**11%**

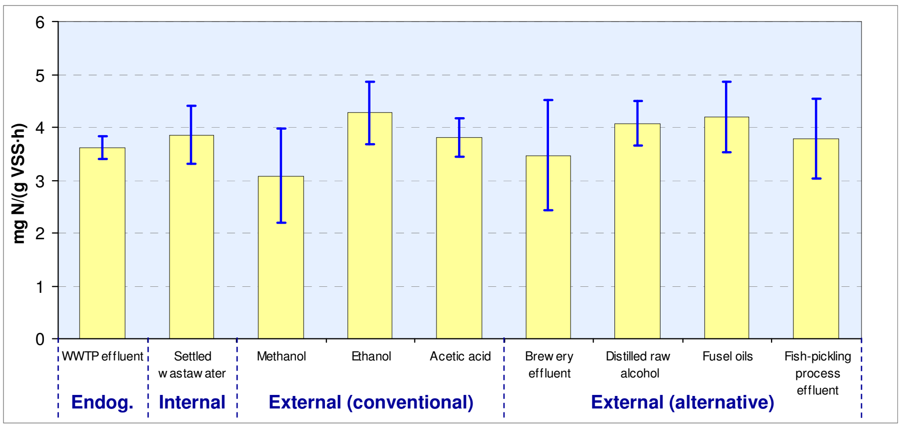
Summary of the conventional NUR measurements with different carbon sources (NUR rates)



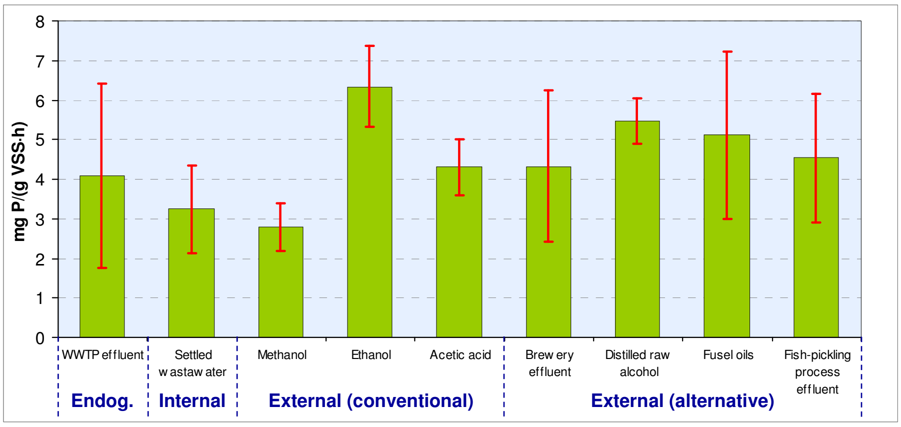
Summary of the conventional NUR measurements with different carbon sources (COD/N ratios)



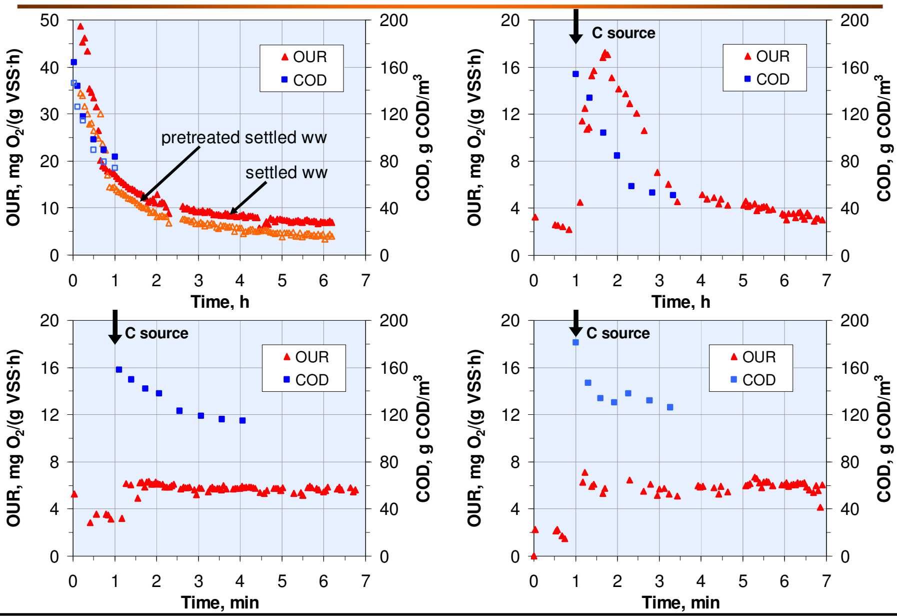
Summary of the NUR measurements during anoxic P uptake with different carbon sources (NUR rates)



Summary of the NUR measurements during anoxic P uptake with different carbon sources (PUR rates)



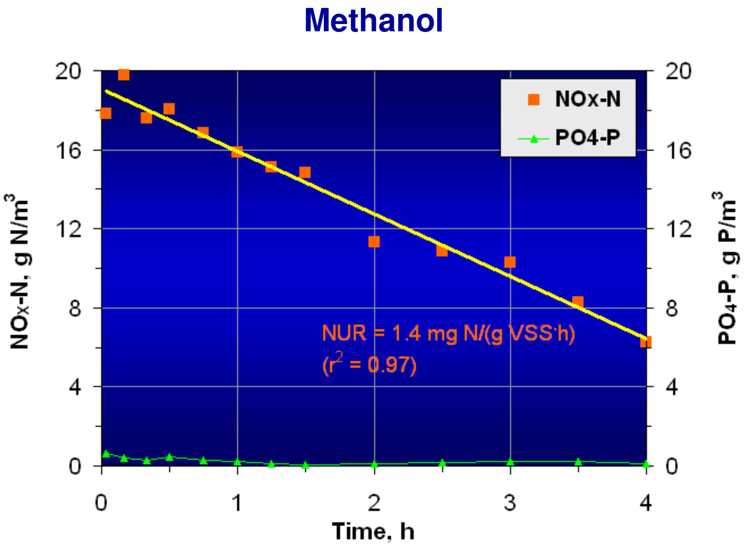
Examples of the conventional OUR measurements



Summary of the conventional OUR measurements

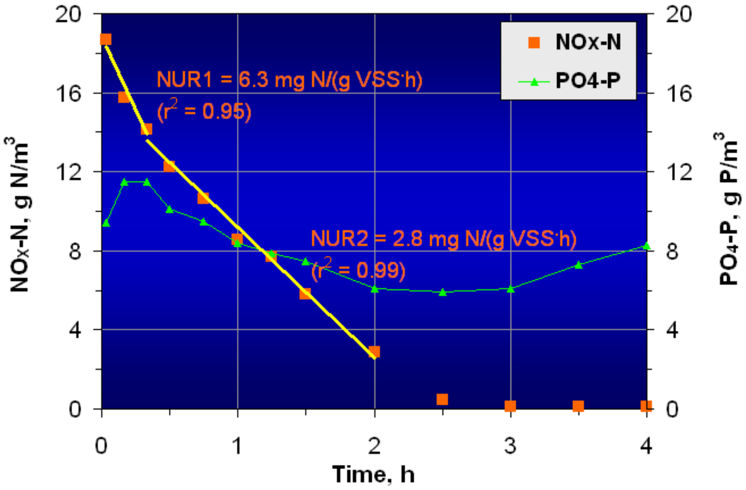
Carbon source	Number of assays	1st assay	2nd assay	3rd assay	4th assay	Average value
		g COD/g COD				
Settled wastewater	4	0.60	0.69	0.66	0.65	0.65
Acetic acid	4	0.77	0.74	0.76	0.78	0.76
Ethanol	4	0.72	0.71	0.74	0.69	0.72
Distilled raw alcohol	3	0.70	0.79	0.66		0.72
Fusel oil	2	0.76	0.79			0.78

Biomass acclimation to methanol (1)



Biomass acclimation to methanol (2)

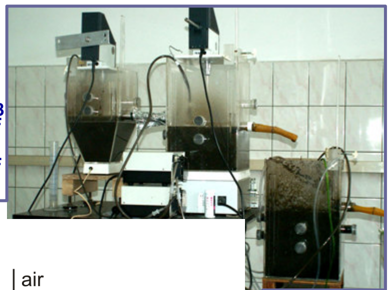
Real (settled) wastewater

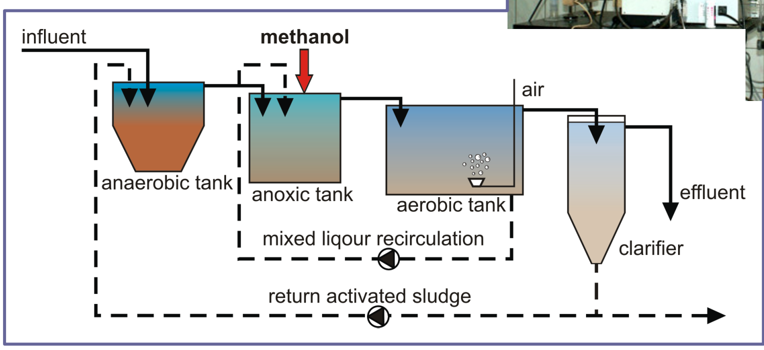


Biomass acclimation to methanol (3)

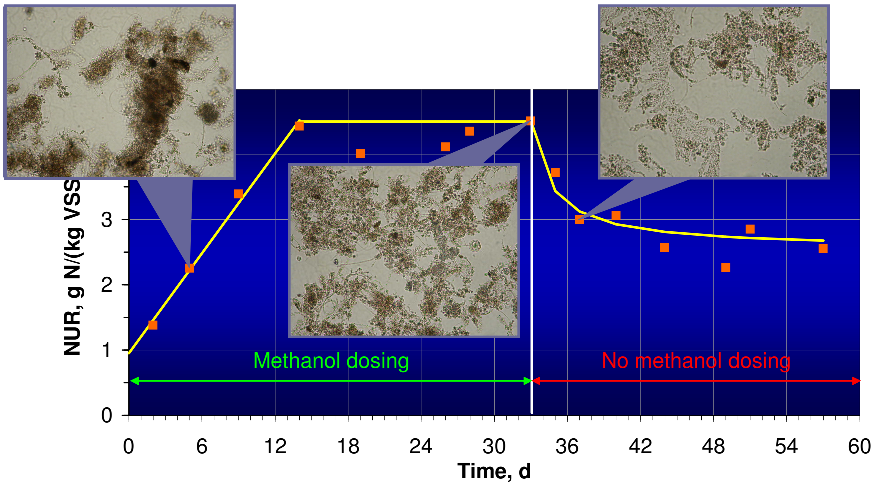
METHANOL DOSAGE:

- Influent (Q_{INF}) - 74 dm³/d
- COD concentration - 350 g COD/m³
- Return activated sludge - 100% Q_{INF}



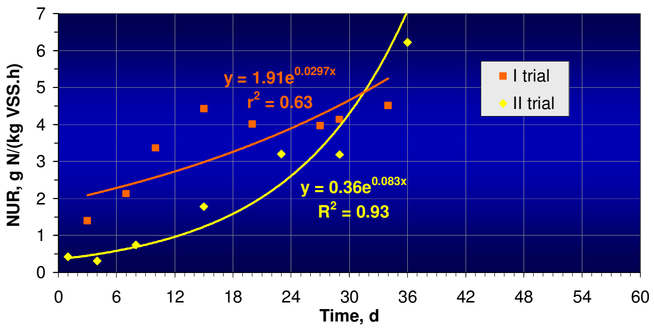


Biomass acclimation to methanol (4) – I trial



Biomass acclimation to methanol (5) – II trial

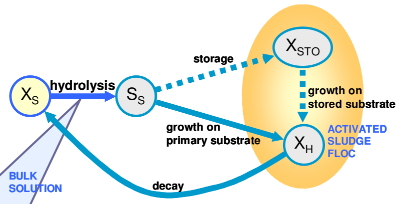
JHB SYSTEM with an automatic control



Modeling hydrolysis process - planned

Hydrolysis process rate equations:

$$
r_{hyd} = \begin{cases}
k_{hyd,0} \\
k_{hyd,I}\, X_S \\
k_{hyd,II}\, X_H \\
k_{hyd,III}\, X_S\, X_H \\
k_{hyd,IV} \cdot \dfrac{X_S}{K_{X,IV} + X_S} \cdot X_H \\
k_{hyd,V} \cdot \dfrac{X_S / X_H}{K_{X,V} + X_S / X_H} \cdot X_H \\
k_{hyd,VI} \cdot \left(\dfrac{X_S/X_H}{K_{X,VI} + X_S/X_H} \cdot \dfrac{S_O}{K_{O,hyd} + S_O} \cdot X_H + \eta_{NO3,hyd} \cdot \dfrac{X_S/X_H}{K_{X,VI} + X_S/X_H} \cdot \dfrac{K_{O,hyd}}{K_{O,hyd} + S_O} \cdot X_H \right)
\end{cases}
$$



Model ASM2d

Conclusions (1)

- Knowledge of the wastewater characteristics is important for optimization of denitrification and EBPR
- A novel batch test procedure was developed to evaluate the effects of colloidal and particulate substrate on denitrification and EBPR
- The removal of colloidal and particulate fractions by coagulation-flocculation resulted in the reduced process rates
- The examined distillery by-product (fusel oil) appears to be an interesting alternative for commercial compounds when seeking an external carbon source

Conclusions (2)

- **The results of two kinds of batch experiments with the distillery wastewater revealed that:**
  - „conventional" NURs: single NURs (~5 mg N/(g VSS·h)) were close to the rates associated with the utilization of RBCOD in the settled wastewater
  - NURs during anoxic P uptake: noticeably higher (>15%) rates were observed in comparison to the tests with the other carbon sources
- **The operating problem that can arise in practice - a temporal variability of the composition**

Acknowledgements

Innovative crbon source for enhancing denitrification in municipal wastewater treatment plants

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