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Energy consumption and greenhousegases production in WWTPs

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Activated sludge: 100 plus 1 years - New trends and perspectives
Palermo, Italy | 11 May 2015

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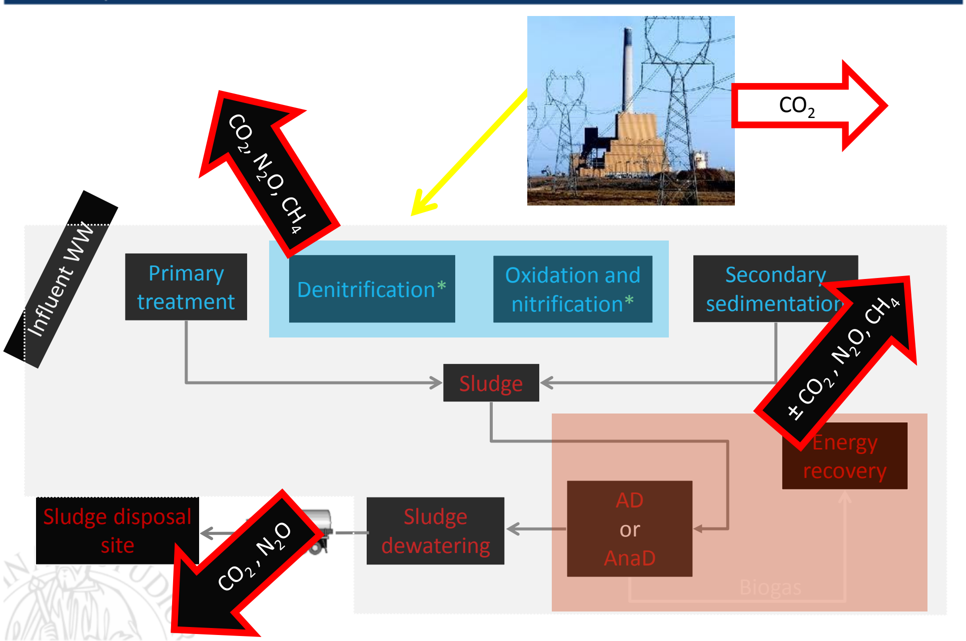
GHGs EMISSION FROM WWTPS



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INTRODUCTION

In 2012 the annual consumption of electricity estimated for Italy was around 300 · 10^9 kWh (Fonte Terna).
It is estimated that about 2,1% (~ 6,4 · 10^9 kWh) of total consumption is due to water cycle (abstraction, water supply, sewers and wastewater treatment (Fonte Terna).

+21% respect to 1999

Considering also consoumption not included in above mentioned estimation (e.g. private plants, agriculture) it is estimated that over 5% (about 15 · 10^9 kWh) of total electricity consumption is due to water and wastewater treatment (Clerici, 2011).

Country	% of energy consumption for water cycle
Sweden	1
UK	3
USA	3,4
Israel	10
ITALY	2,1

Olsson, G. (2011). Water and Energy Nexus. In Encyclopaedia of Sustainability Science and Technology, Springer

3

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INTRODUCTION

The energy consumption due to wastewater treatment has a positive trend due to:

• need of improving the quality of effluents discharged into the environment (e.g. conventional nitrogen removal and/or removal of emerging micropollutants)

• need of reducing the production of biosolids to be treated (stabilization, dewatering, thermal drying) and disposed of

• Aging of infrastructure such as sewers which is responsible for the increasing of infiltration with consequent increase of pumping costs

• Optimization of existing plants without changes in the treatment train (increase of energy efficincy)

• Change of treatment train to use less energy demanding processes

4

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INTRODUCTION

Possible interventions:

Centralization of wastewater treatment (to be verified)
Larger plants are characterized by lower specifci energy consumpotion :

- On average 22 kWh/a.e. per year in the range 30.000 - 1.100.000 p.e.
- On average 43 kWh/a.e. per year in the range <30.000 p.e.

• installation of VFD are use of high efficiency devices

• anaerobic digestion of sludge eventually coupled to pre-treatment aimed at increasing biogas production;

• in case of anaerobic digetion of sludge use cogeneration for electricity and heat recovery from biogas;

5

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ENERGETIC CONSPUMPTION OF AERATION

- In conventional activated sludge plants, energy demand is largely dominated by the aeration. Considerable savings are possible by optimising its design and operation;
- The energy consumption of aeration systems depends on the efficiency of its components, the characteristics of wastewater and operating conditions of the plant;
- It is therefore necessary to perform a series of measurements to verify the aeration system's behaviour in process conditions;
- Also estimation and reduction of both direct and indirect GHGs emitted by WWTPs is of great concern.

This research aimed at using off-gas testing method for:

- monitoring and improving oxygen transfer efficiency in a large WWTP located in Florence (Tuscany, Italy);
- monitoring GHG's emission from the oxidation tank of the plant.

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ENERGETIC CONSPUMPTION OF AERATION

Optimization of aeration system devices:

- Compartimentalized aeration;
- Intermittent aeration;
- DO control in aerobic tanks ***(1-2 mg/l)***

  Highr DO values are responsible for :

  ✓ The increase in the energy required for oxygen transfer from the gas to the liquid phase (reduction of OTE)

  ✓ The reduction of sludge settling velocity

  ✓ A negative impact on the anoxic zone aimed at nitrogen removal (denitrificatrion)

$$AE = \frac{OTR}{P} = \frac{\rho_{O_2} \cdot Q_{AIR} \cdot OTE}{P} =$$

$$= \frac{\rho_{O_2} \cdot Q_{AIR}}{P} \frac{\alpha \cdot SOTE \cdot (\beta \cdot C_{S,pwT} - DO)}{C_{S,20} \cdot \theta^{(20-T_W)}}$$

7

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ENERGETIC CONSPUMPTION OF AERATION

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WEF and ASCE estimate that an effcient and strict control of DO in aerobic tanks can allow a **10-30 % savings of total energy consumption in wastewater treatment**

8

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ENERGETIC CONSPUMPTION OF AERATION

Fine-bubble diffusers

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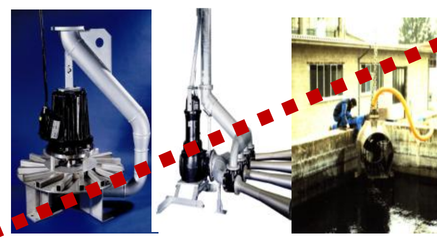
Tubular diffusers

Mechanical aerators



3.4   5 kgO_2/kWh (S.A.E.)
1.5 2.8 kgO_2/kWh (A.E.)

2.3 3.6 kgO_2/kWh (S.A.E.)
1.2 1.9 kgO_2/kWh (A.E.)

0.8 2.2 kgO_2/kWh (S.A.E.)

0.6 1.5 kgO_2/kWh (A.E.)

9

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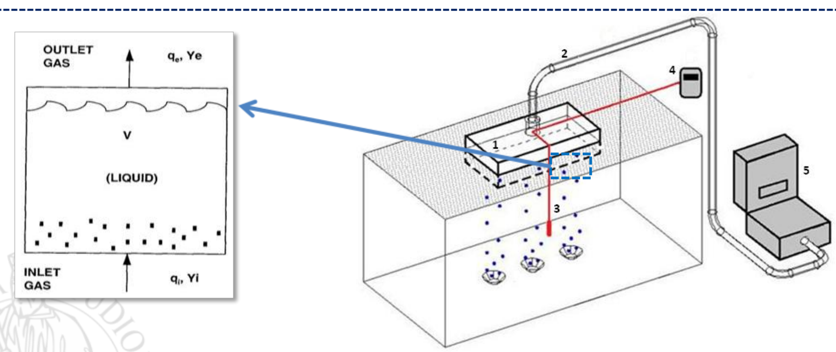
OFF-GAS TEST

The ***off-gas method*** is a tecnique developed for monitoring the oxygen transfer efficiency of air diffused aeration systems (*Redmon et al., 1983*).

Mass balance of oxygen in gas phase

Oxygen transferred to the liquid phase = oxygen removed from the gas phase

$$OTE\ [\%] = \frac{O_{2\ IN} - O_{2\ OUT}}{O_{2\ IN}} \cdot 100$$



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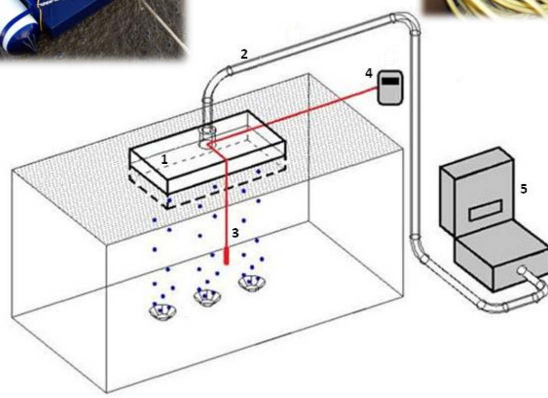
OFF-GAS TEST

1. Hood for off-gas collection
2. Connection pipe between the hood and the analyzer

3. LDO probe

4. Oxymeter



5. Off-gas analyzer

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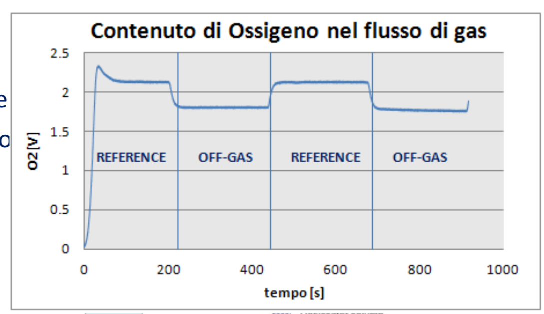
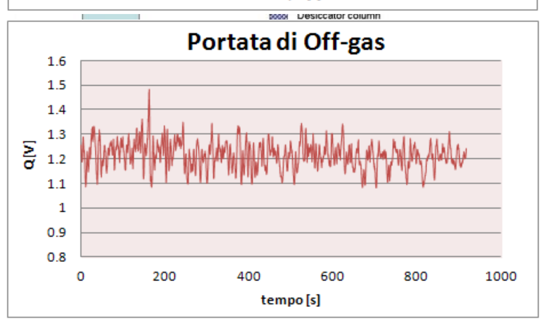
OFF-GAS TEST

Off-gas analyzer

- Measurement of oxygen conce
- Measurement of the off-gas flo





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OFF-GAS TEST

CALCULATED AND ESTIMATED PARAMETERS:

- Transfer efficiency in process conditions (OTE, %):

$$OTE = \frac{Y(O_{2,ref}) - Y(O_{2,O-G})}{Y(O_{2,ref})} \cdot 100$$

- Transfer efficiency in standard conditions in process water (αSOTE, %):

$$\alpha SOTE = \frac{C_{S,20} \cdot OTE \cdot \theta^{(20-T_w(°C))}}{(\beta \cdot C_{S,pwT} - DO)} \cdot 100$$

$C_{s,20}$: saturation concentration @ 20°

$C_{s,pwT}$: saturation concentration @ process conditions

β = 1- (0.01 TDS)/1000

- α-factor: $\alpha = \alpha SOTE/SOTE$

- oxygen transfer rate (OTR, KgO_2/h):

$$OTR = K_L a \cdot (C_{S,pwT} - DO) \cdot V = \rho O_2 \cdot OTE \cdot Q_{air}$$

- Aeration efficiency (AE, $Kg0_2/kWh$):

$$AE = OTR/P$$

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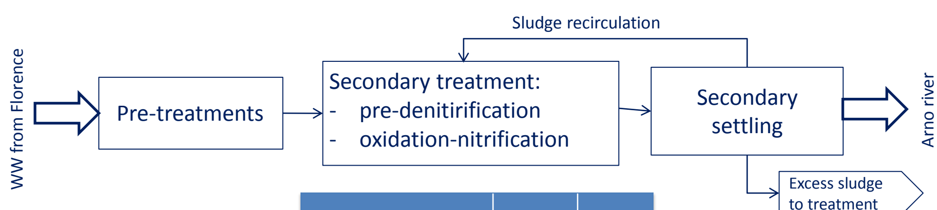
San Colombano WWTP



Potenzialità	600000	P.E.
Portata in ingresso	240000	m³/d
Età del fango	20-30	d

Parameter	Unit	IN*	OUT*
$N\text{-}NH_4^+$	mg/l	19.4	0.51
$N\text{-}NO_2^-$	mg/l	-	n.d.
$N\text{-}NO_3^-$	mg/l	-	6.8
Ntot	mg/l	19.9	8.4
BOD	mg/l	48.3	3.6
COD	mg/l	145.6	16.8
P	mg/l	2.42	1.71
SST	mg/l	94.6	4.9

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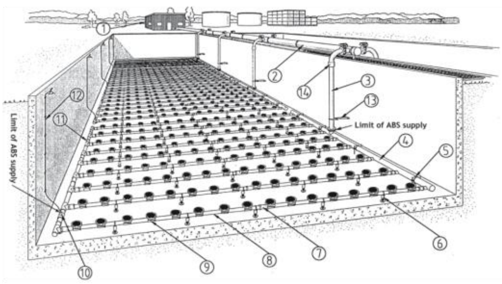
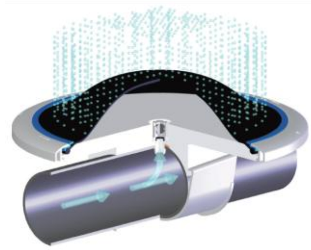
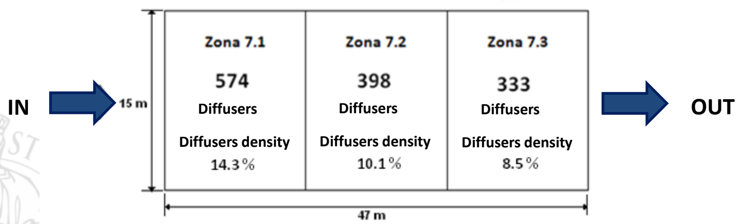
San Colombano WWTP

AERATION SYSTEM



Microforated disks ABS PIK 300®
Area of diffuser = 0.06 m^2
Diffusers/line = 1305





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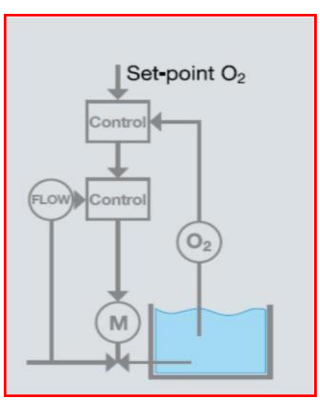
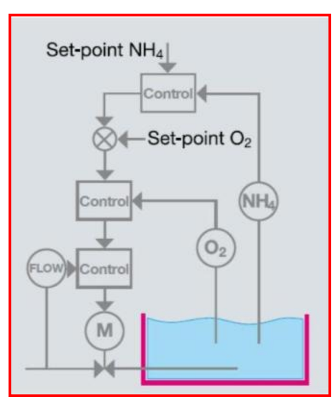
IMPROVEMENT OF AIR FLOW RATE CONTROL

Air flow rate management was shifted from a DO set-point control to an ammonia-DO cascade control



BEFORE:
Air flow rate managed on the basis of DO set-point



AFTER:
Air flow rate managed on the basis of N-NH$_4^+$ in the effluent and DO set-point

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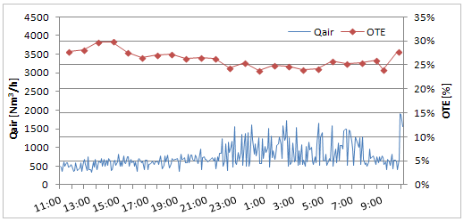
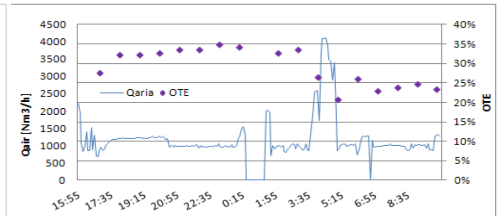
IMPROVEMENT OF AIR FLOW RATE CONTROL

Comparison of OTE between the two different strategies





DO set-point control	ammonia-DO cascade control
OTE ≈22-30%	OTE ≈24-35%

The new strategy for air flow rate control allowed to reduce the average DO concentration in the oxidation tank which in turn allowed to increase the oxygen transfer efficiency

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IMPROVEMENT OF AIR FLOW RATE CONTROL

As a consequence the aeration efficiency improved as well:

$$AE = \frac{OTR}{P} = \frac{\rho_{O_2} \cdot Q_{AIR} \cdot OTE}{P} = $$

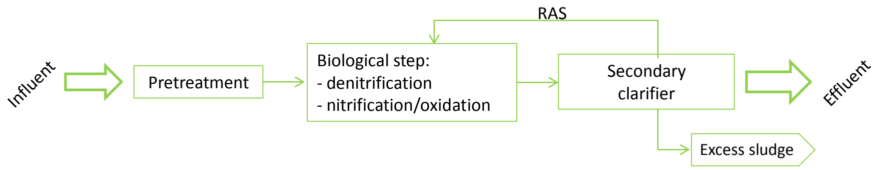
$$= \frac{\rho_{O_2} \cdot Q_{AIR}}{P} \frac{\alpha \cdot SOTE \cdot (\beta \cdot C_{S,pwT} - DO)}{C_{S,20} \cdot \theta^{(20-T_W)}}$$

DO ↓ ⟹ AE ↑

For the S. Colombano WWTP, a relative increase of 10% in terms of OTE allows to save about **500MWh/y** which means **75000 euro/y**

→ **203.000 $kgCO_{2,eq}$/y** (@ 0,406 $kgCO_{2,eq}$/kWh)

SMALL WWTP



Currently there is a rectangular single tank in which takes place both oxidation-nitrification and denitrification through an intermittent aeration process

Location	Tuscany (Italy)	
Type	municipal	
Potentiality	3500	p.e.
Influent flow	900	m^3/d
MLSS	3.5	g/l

Oxidation tank characteristics

SMALL WWTP

Aeration system:

Type	MEMBRANE PANEL
Installation year	2010
Size [m^2]	4 x 0.18
SOTE [%]	34.2
n° diffusers	24 (4 extractable frames of 6 panels each)

The air flow is intermittent in order to alternate in the tank aerobic and anoxic conditions

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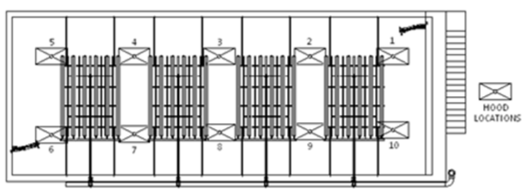
SMALL WWTP

Three off-gas tests were carried out on the aeration system of this plant:

- June 2010: immediately after the installation of the membrane panels
- May 2012: after two year's operation during which had not been carried out any cleaning operation
- July 2012: immediately after carrying out a cleaning operation of diffusers with peracetic acid

For each test the measurement were taken in 10 different location inside the tank.

tank coverage over 2%



Between the first and second tests the blower of the plant was replaced with another one characterized by a lower power

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SMALL WWTP

Test	Diffusers conditions	DO (mg/l)	OTE (%)	αSOTE (%)	α
June 2010	New	4.62	9.8	18.0	0.53
May 2012	2 years' service	0.01	9.4	9.5	0.30
July 2012	Cleaned	3.70	9.2	15.8	0.46

Taking all the specific site characteristics into account, the test could be considered positive for αSOTE value higher than or equal to 15%

- The membrane panels are characterized by high performance
- The value provided by the manufacturer and used during sizing are representative of the system

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SMALL WWTP

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After two year's operation there was a halving in the performance of the diffusers

⇨ this reduction was attributed to the gradual fouling of diffusers with operation time (favored by different operating conditions)

⇩

Following the results obtained it was decided, together with plant service provider, to carry out a cleaning of the diffusers

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SMALL WWTP

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- After the cleaning of diffusers, a net improvement in the αSOTE's value was observed
- The concentration of DO in the tank, with the same air flow, increased in a significant manner reaching average value of 3.7mg/l during aerobic phase

⇩

- The loss of system efficiency was really due to the diffusers fouling
- the cleaning operation produced a 6% recovery in terms of αSOTE

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SMALL WWTP

Comparison between the air flows obtained for the same position in different test:

Off-gas flow rate	Sampling positions 1	2	3	4	5	6	7	8	9	10
May_{2012} vs. $June_{2010}$	0.45	0.40	0.36	0.29	0.56	0.48	0.67	0.56	0.49	0.50
$July_{2012}$ vs. May_{2012}	1.06	2.06	1.07	2.30	1.57	0.73	1.77	0.98	1.64	1.72

- Flows measured in May 2012 are lower than those measured in 2010 due to a blower replacing
  the reduction is of the same magnitude for all position
- In July 2012 an off-gas flow increase was recorded in nearly all the point monitored

These results confirm the oxygen transfer efficiency data

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SMALL WWTP

The fact of being able to quantify the changes of efficiency of the aeration system makes possible to quantify the effect of the aeration system efficiency on the energy consumption of the plant:

Test	αSOTE (%)	Air flowrate* (Nm^3/h)	Energy consumption (kWh/year)	kWh COD_{rem}	Aeration costs (€/years)	€ COD_{rem}
June 2010	18.0	290	42048	0.65	6307	0.10
May 2012	9.5	545	71832	1.11	10774	0.17
July 2012	15.8	330	43800	0.68	6570	0.10

* Air flow necessary to guarantee an SOTR=26kgO_2/h assuming 0.55 as α-value

- A reduction in the αSOTE value makes an increase in management costs by approximately 4500€/y
- The maintenance operation allowed for reducing the annual energy consumption to the initial value, approximately 10kWh for p.e.
- Assuming 0.406 kgCO_2/kWh as specific emission (IEA,2012), the energy saving due to cleaning corresponds to 11.4 tCO_2/y and 3.25 KgCO_2/p.e.

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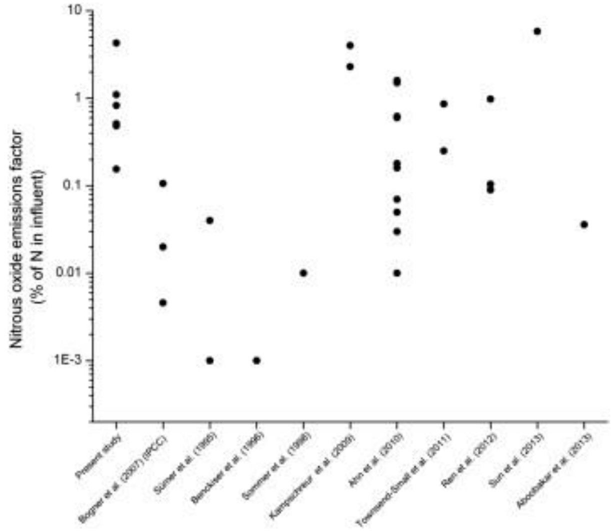
NITROUIS OXIDE EMISSION



Yoshida et al. Plant-integrated measurement of greenhouse gas emissions from a municipal wastewater treatment plant. Wat. Res., 61, 2014, 108 – 118.

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CONCLUSIONS

- Optimization of aeration system is one of the main methods to reduce energy consumption in WWTPs
- Overall reduction of GHGs emission requires the measurement of both direct and indirect GHGs emissions
- Off-gas test proved to be a successful method for monitoring the oxygen transfer efficiency in operating conditions;
- information gathered with off-gas testing allow to optimize the oxygen transfer efficiency through the adotpion of appropriate control process strategies
- Measurement of oxygen transfer efficiency in different operating conditions allows to estimate ex-ante the potential energy and economic savings in case of advanced management of air flow rate in oxidation tanks;
- Off-gas test can give, at the same time, information about oxygen transfer efficiency (and therefore GHGs indirect emissions) and direct GHGs emission from the oxidation tank.

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ACKNOWLEDGEMENTS

Thank you for your attention!

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