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carbon footprint of Wastewater
nt plant

e oxygen transfer efficiency of full-scale
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New trends and research perspectives
towards a more sustainable environment
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- 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.

The off-gas method has proved to be an effective technique that offers several advantages for testing diffused air aeration systems in full-scale conditions.

Oxygen transfer rate (kgO_2/h)

$$OTR = \int_V k_L a (C_S - C) dV$$

Driving force

Liquid side mass transfer coefficient

Oxygen transfer efficiency

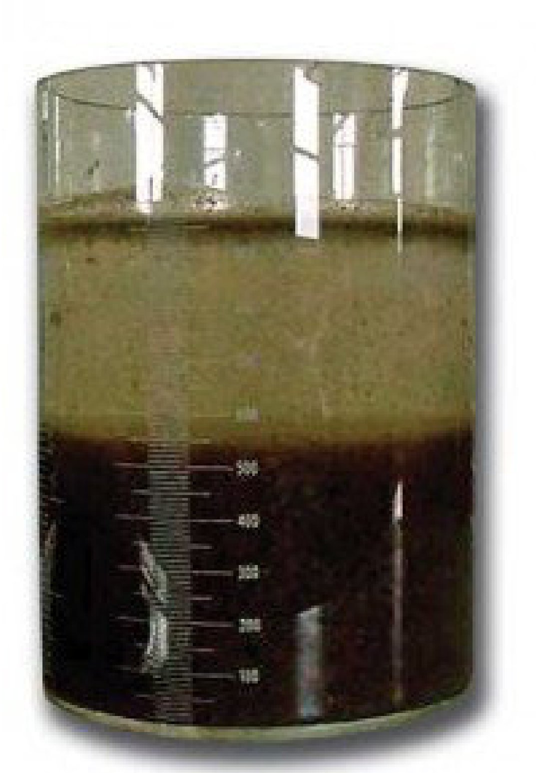
$$OTE\ [\%] = \frac{O_{2\ IN} - O_{2\ OUT}}{O_{2\ IN}} \cdot 100$$

Therefore, results are tipically reported to STANDARD OXYGEN TRANFER EFFICIENCY:

SOTE [%]

Technology providers measure air diffusers systems performance in standard conditions (SOTE): that are quite different from the real ones. The biggest difference is in the water.

TAP WATER



MIXED LIQUOR

Translating standard conditions to process conditions

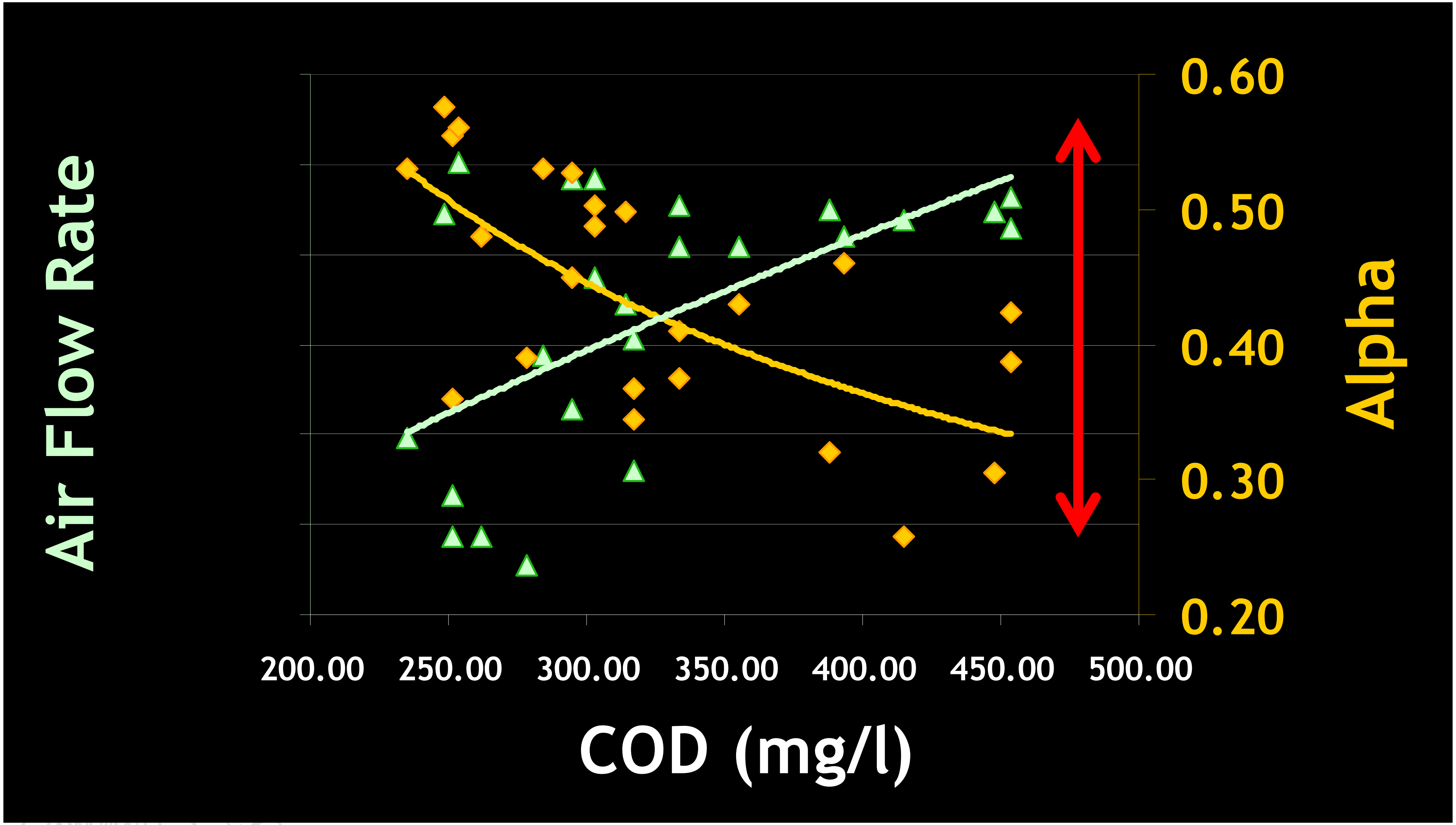
It usually requires the use of several site-specific empirical parameters, such as:

$$\alpha = \frac{(k_L a)_{processwater}}{(k_L a)_{cleanwater}} \qquad \alpha = \frac{\alpha SOTE}{SOTE}$$

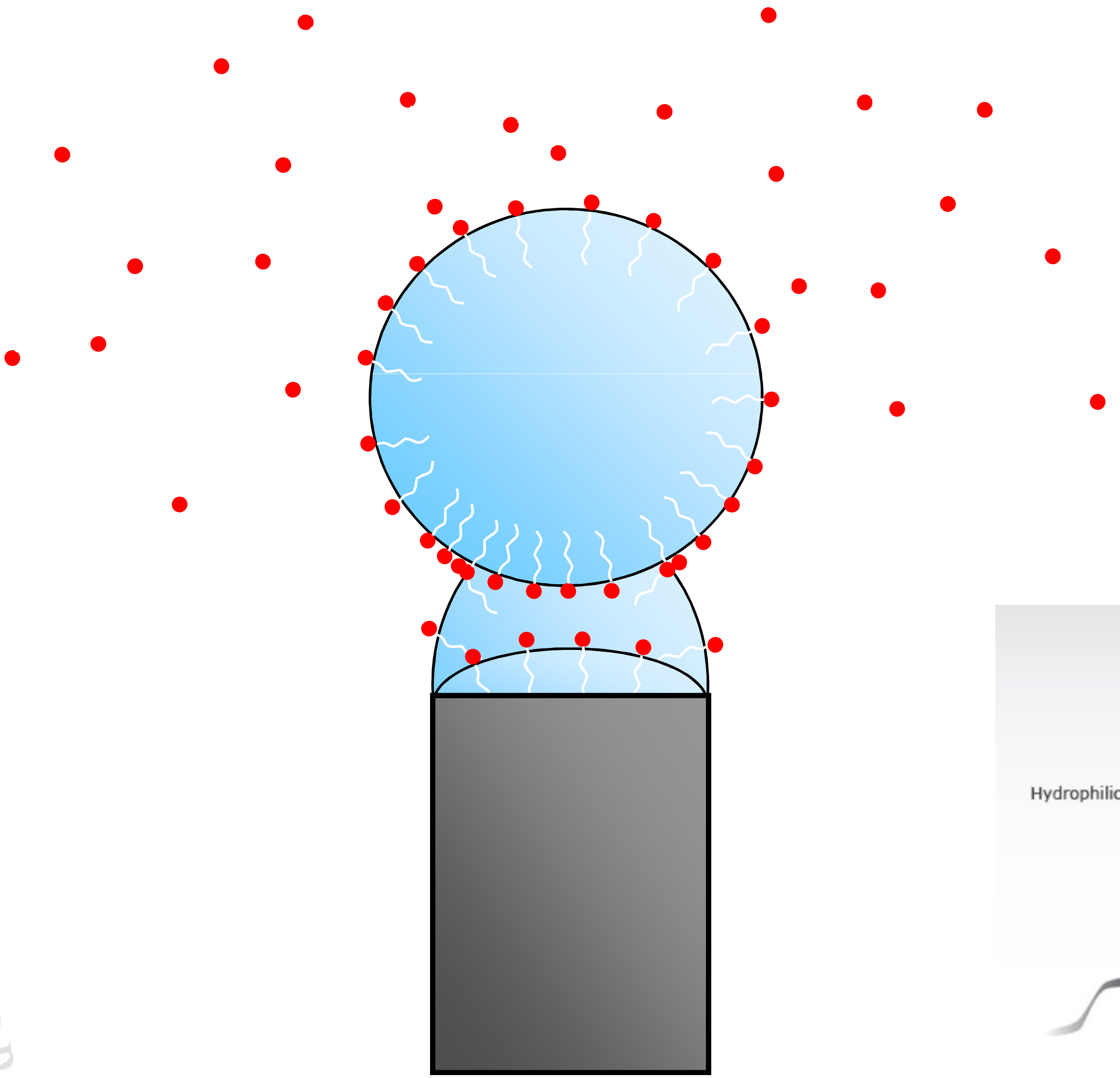
Where αSOTE is the oxygen transfer efficiency in process water at standard conditions except for the effect of contaminants on the mass transfer coefficient.

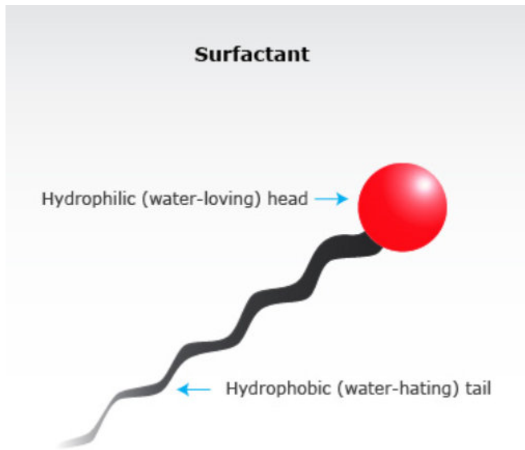
For fine-bubble systems designer use often α=0.6

Dynamics of alpha vs. organic load



SURFACTANT INTERFACIAL ACCUMULATION



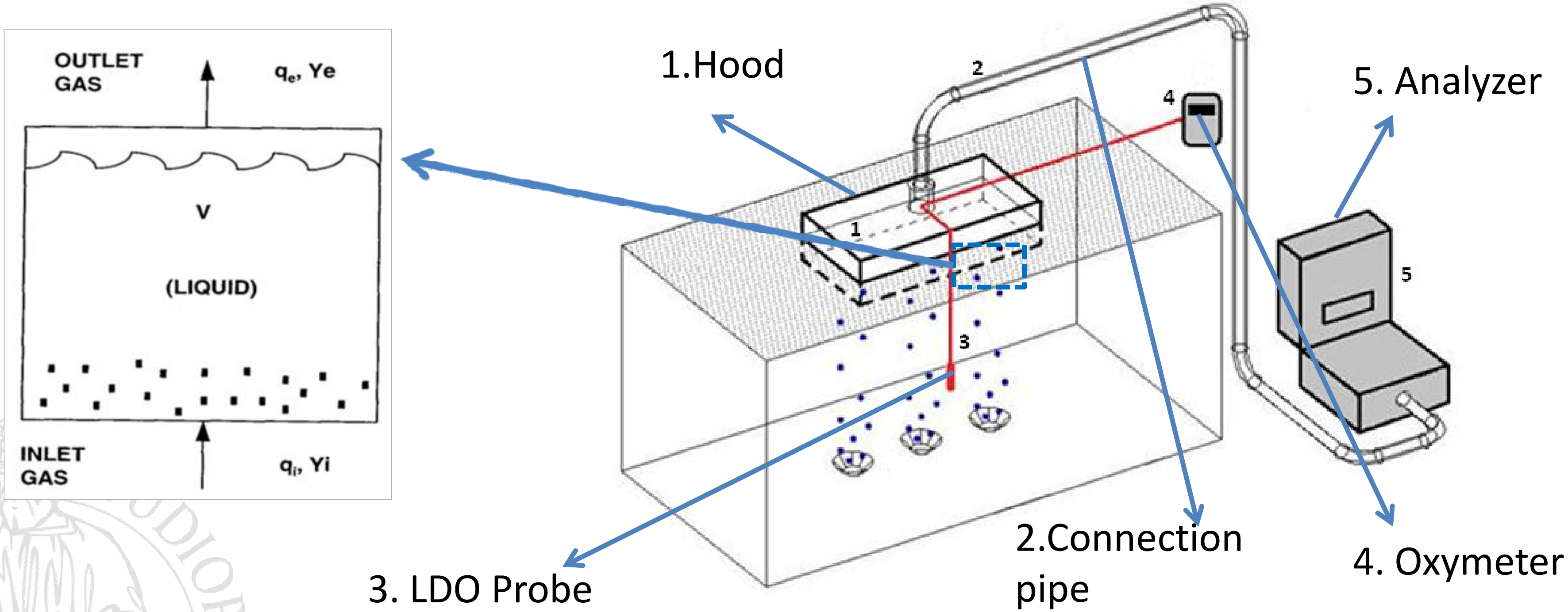


The ***off-gas method*** is a tecnique developed for monitoring the oxygen transfer efficiency of air diffused aeration systems (*Redmon et al., 1983*).

Mass balance of oxygen in gas phase

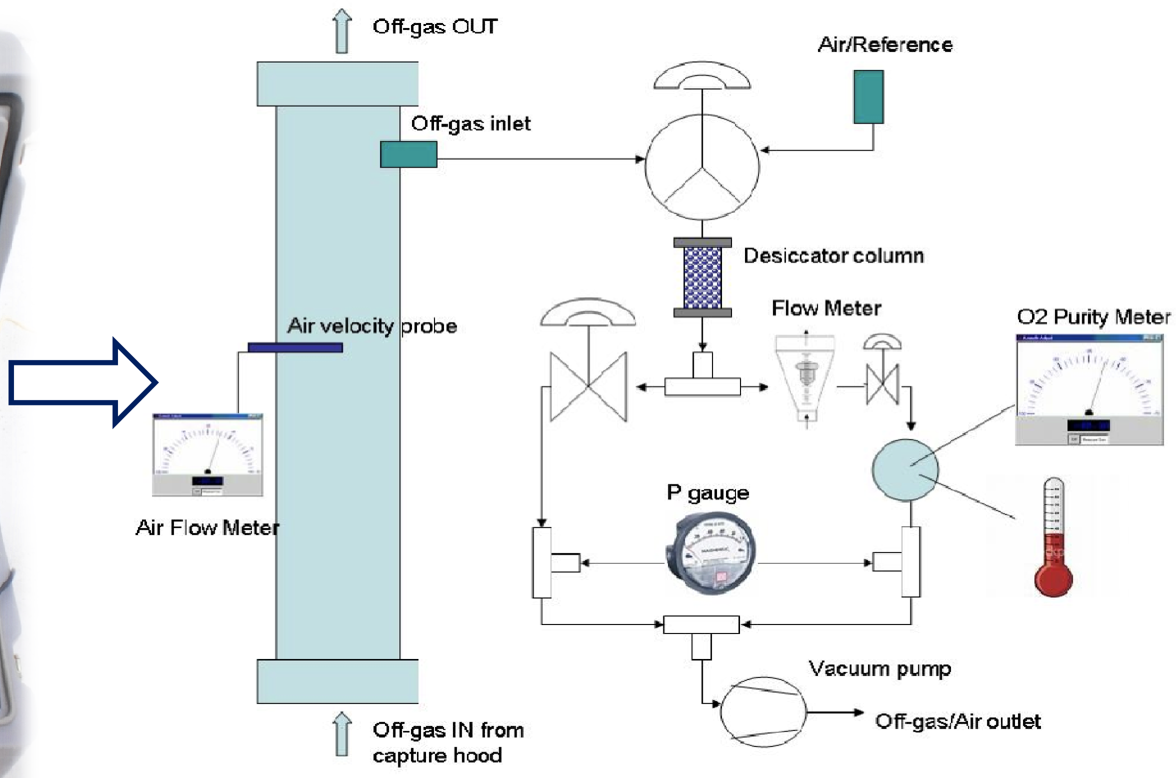
Oxygen transferred to the liquid phase = oxygen removed from the gas phase

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



Off-gas analyzer

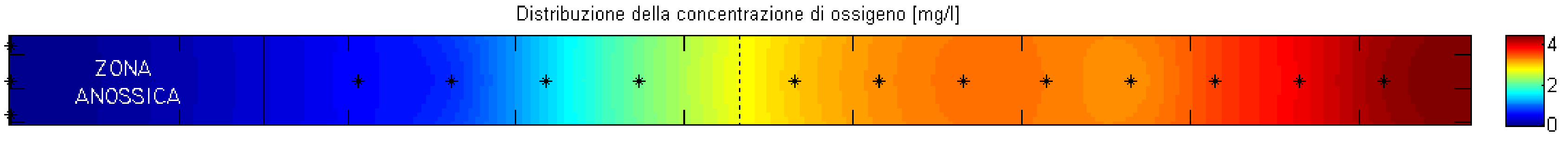
- Measurement of oxygen concentration in air (*Reference*) and in the off-gas
- Measurement of the off-gas flow rate collected from the hood



1.Define a sampling grid depending on the geometry of the tank and the aeration system

2. Put the collection device in a point on the surface of the tank according to the sampling grid

3. For each position, alternatively measure oxygen content in the ambient air (reference) and the off-gas, and measure other required parameters



The experiments concerning the oxygen transfer efficiency were carried out within the AERE project funded by the Italian Ministry for Environment, Land and Sea. We tested several plants with different characteristics in terms of:

- Plant size;
- Diffusers;
- Wastewater characteristics;
- Operating conditions;
- Instrumentation and control;
- Management of air flow rate.

The Civil and Environmental Engineering Dept. of the University of Florence is the leading partner of the project. Other partners:

acea acqua
Acea Ato 5 SpA

Utilitatis
pro acqua energia ambiente

GORI
GESTIONE OTTIMALE RISORSE IDRICHE

acquedotto pugliese
l'acqua, bene comune

MASSA
SPIN-OFF
MONITORING OF RISK

UMBRA ACQUE

Publiacqua

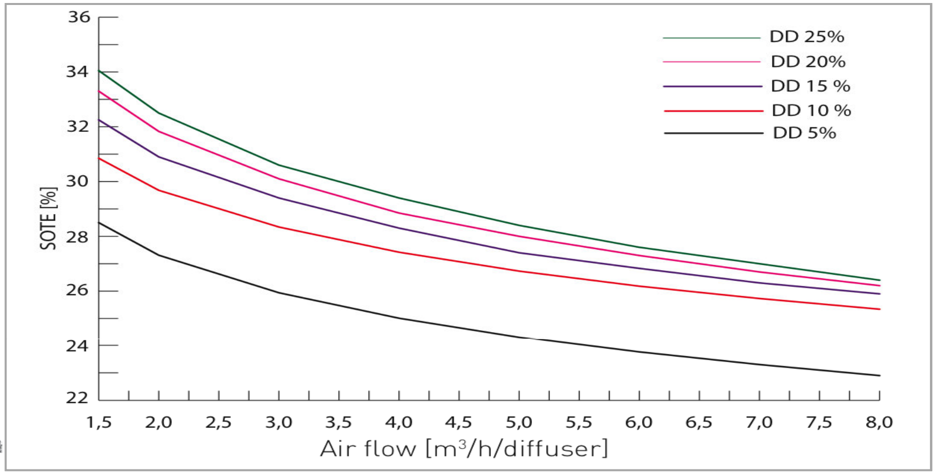
INGEGNERIE TOSCANE

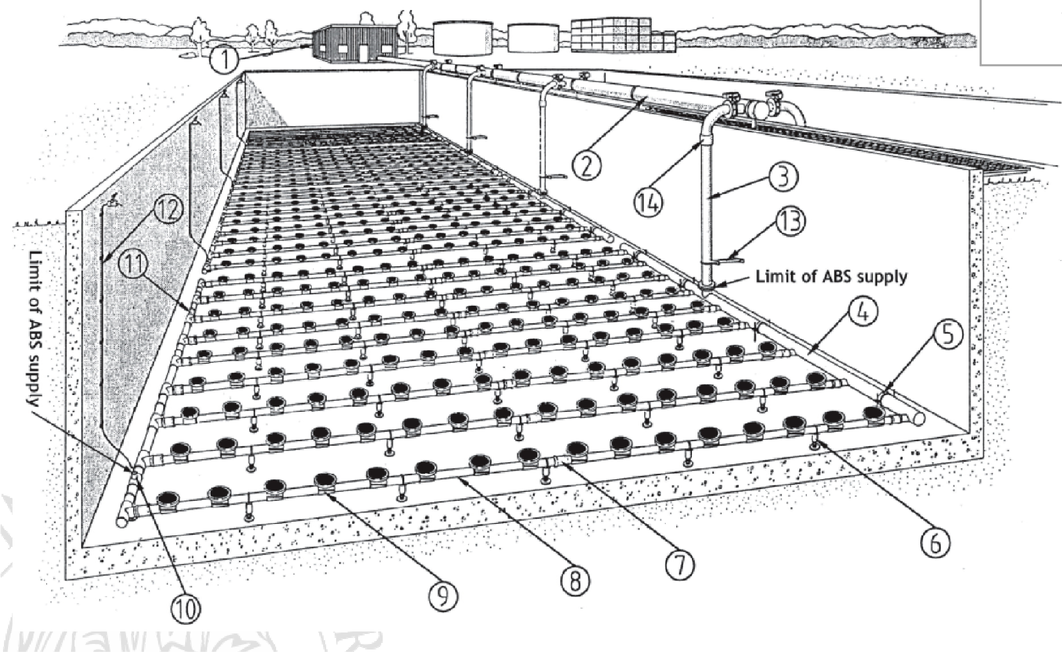
TESTED AIR DIFFUSED AERATION SYSTEMS:

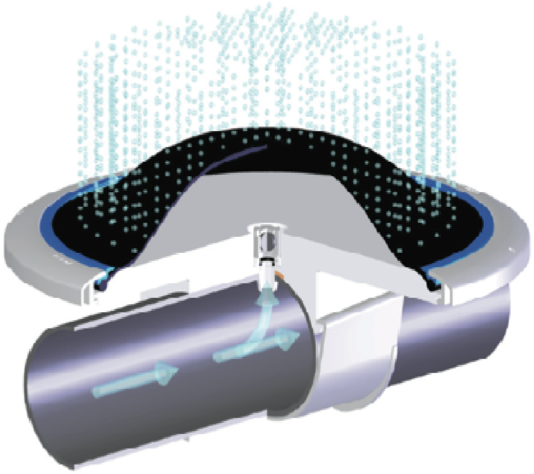
1- Membrane disc diffusers

Type	9”	13”
Unitary area [m^2]	0.038	0.06
Range of air flow rate [Nm^3/h per diffuser]	1.0-7.0	1.5-8.0
Tested density [%]	8.0-10.8	8.5-14.6

Data provided from the manufacturer





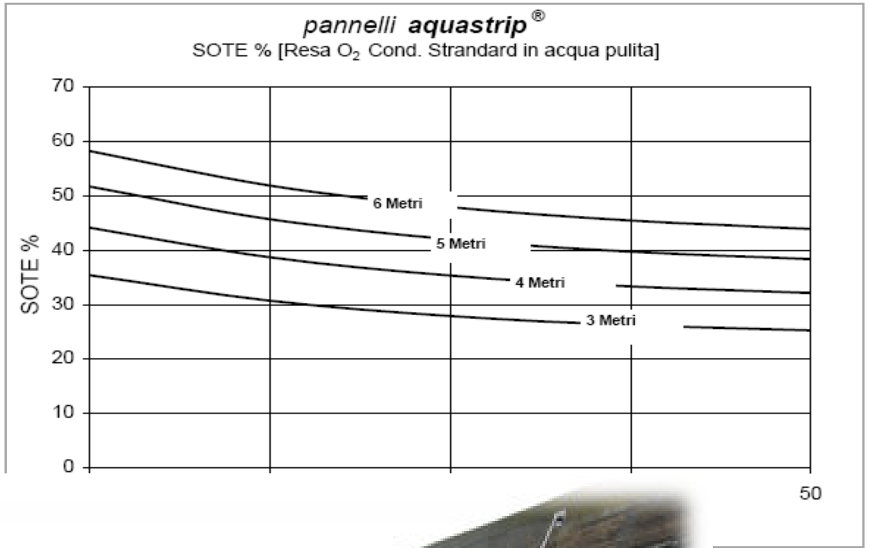


TESTED AIR DIFFUSED AERATION SYSTEMS:

- MEMBRANE PANELS

Data provided from the manufacturer

Type	Q 3.0 EU	P 4 EU 180
Unitary Area [m^2]	0.53	0.72
Range of air flow rate [Nm^3/h per diffuser]	5.0-60.0	7.0-84.0

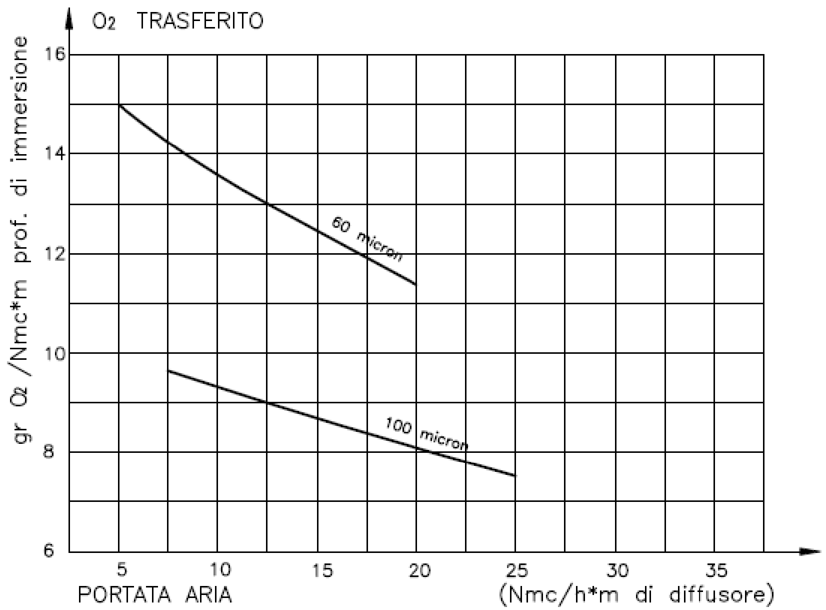


TESTED AIR DIFFUSED AERATION SYSTEMS:

3 – TUBOLAR DIFFUSERS

Type	**ECO 1504**
Diameter [mm]	70
Lenght [mm]	750

Data provided from the manufacturer



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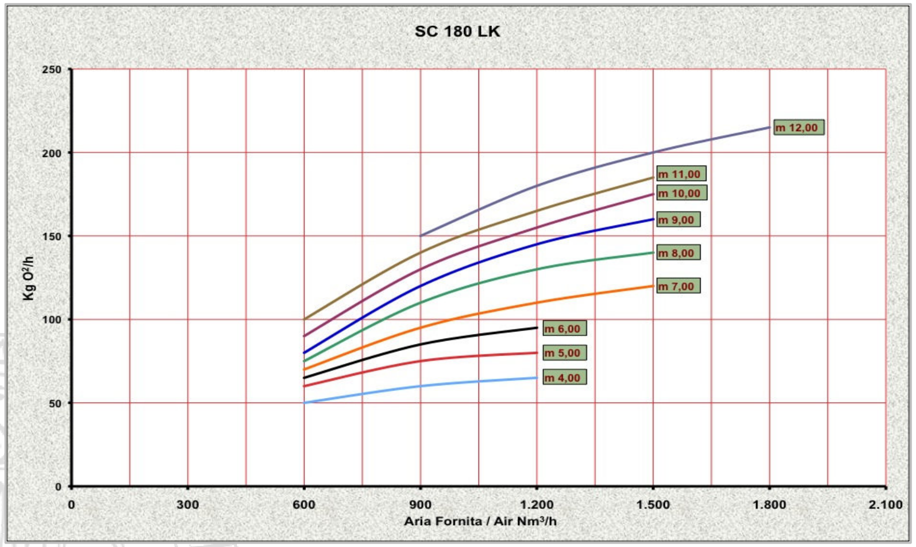
TESTED AIR DIFFUSED AERATION SYSTEMS:

4 - PRESSURIZED SUBMERGED AERATOR

Air flow rate	600-2200 Nm^3/h
Maximum power	22 KW
rev/min	1450/351
Maximun submergence allowed	12 m

Data provided from the manufacturer



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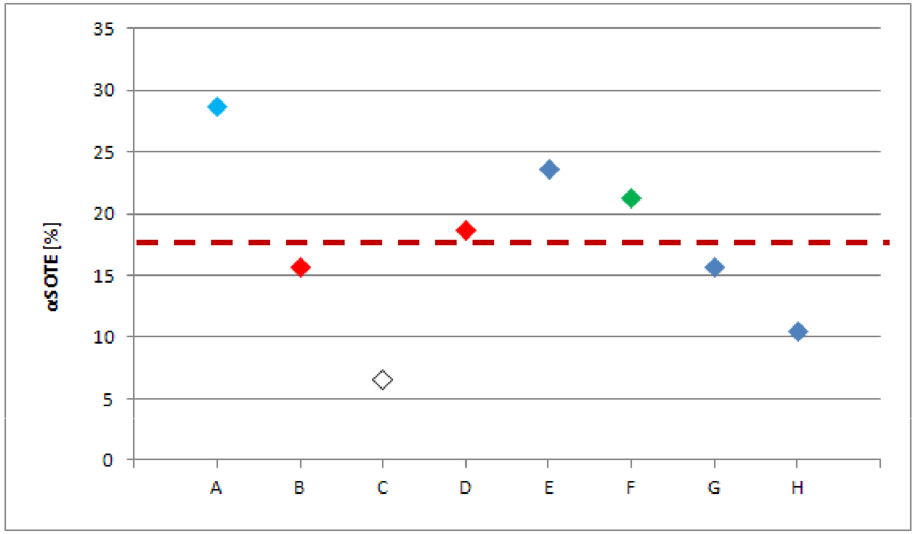
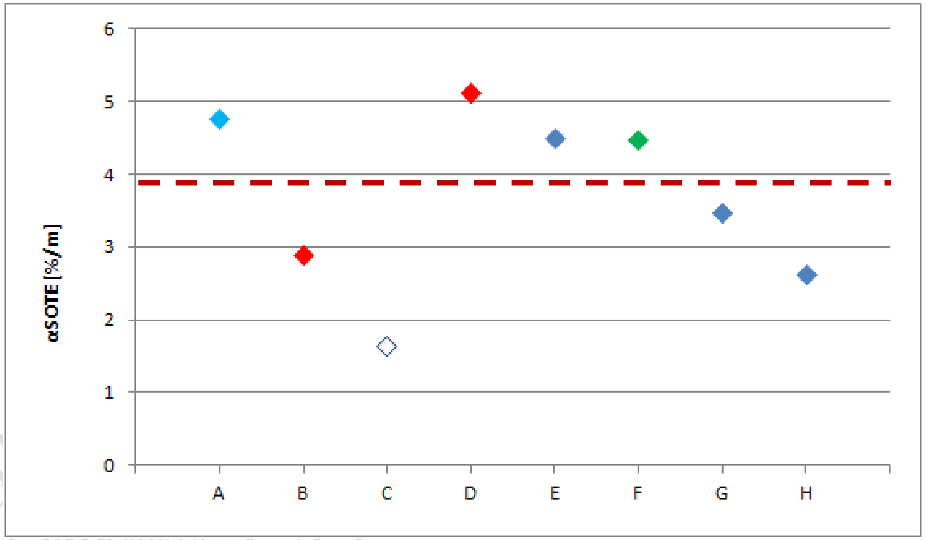
Experimental tests have been carried out in order to:

- Evaluate the mean oxygen transfer efficiency on a daily basis;
- Evaluate the fouling of air diffusers and the efficacy of cleaning interventions;
- Evaluate the distribution of air flow rate and DO concentration within tanks;
- Gather information required to evaluate the potential energy and economic savings in case of advanced management of air flow rate;
- Optimize the operative conditions of the aeration system;
- Estimate the GHGs emission from WWTPs (N_2O, CH_4, CO_2).

• COMPARISON AMONG DIFFUSERS:

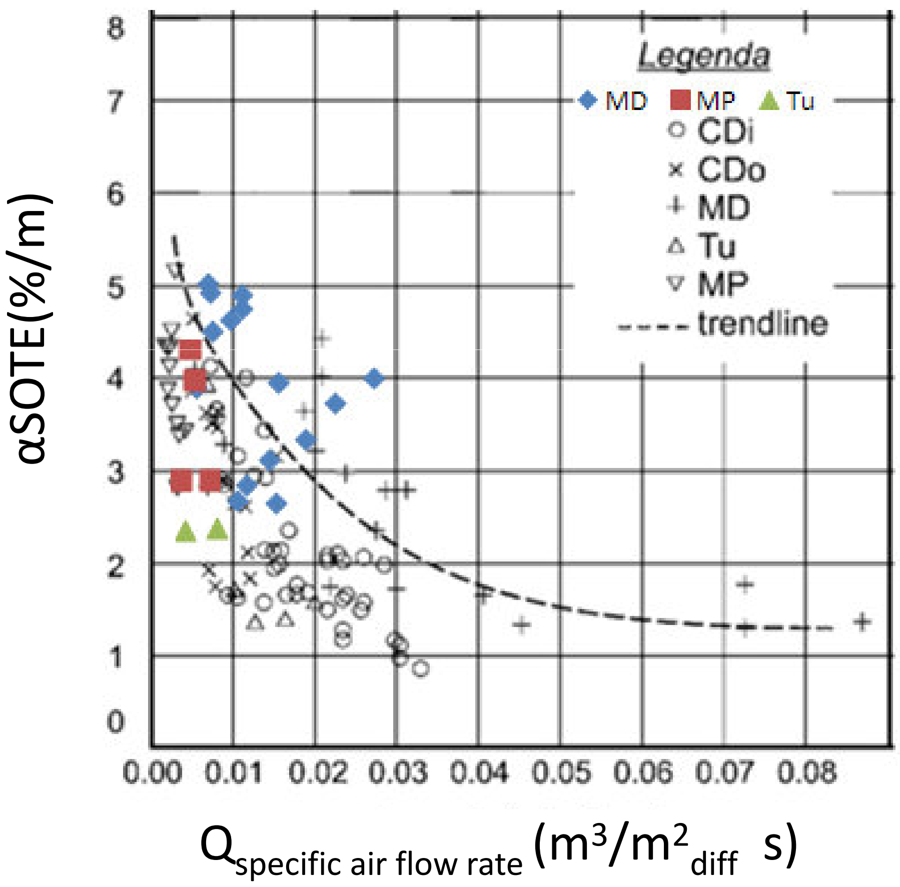




A	Membrane discs 13"
B	Membrane panel 0.53m²
C	Submerged pressurized aerator
D	Membrane panel 0.72m²
E	Membrane discs 9"
F	Tubolar diffusers
G	Membrane discs 9"
H	Membrane discs 9"

αSOTE represents the oxygen transfer efficincy in standard conditions and can be used to compare different systems or similar systems of different plants

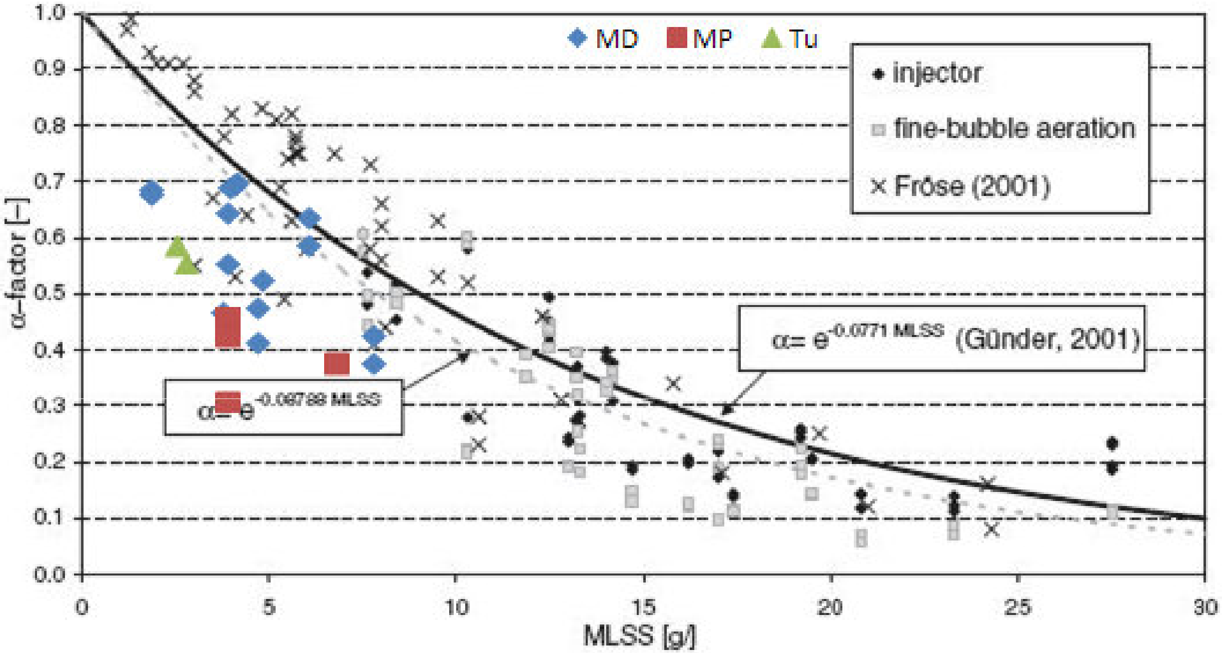
• COMPARISON WITH DATABASE



CDi	Ceramic discs
CDo	Ceramic domes
MD	Membrane discs
Tu	Tubolar diffusers
MP	Membrane panel

Results can be compared with data from many other tests. It gives a first idea of the efficiency of the system.

• COMPARISON WITH DATABASE

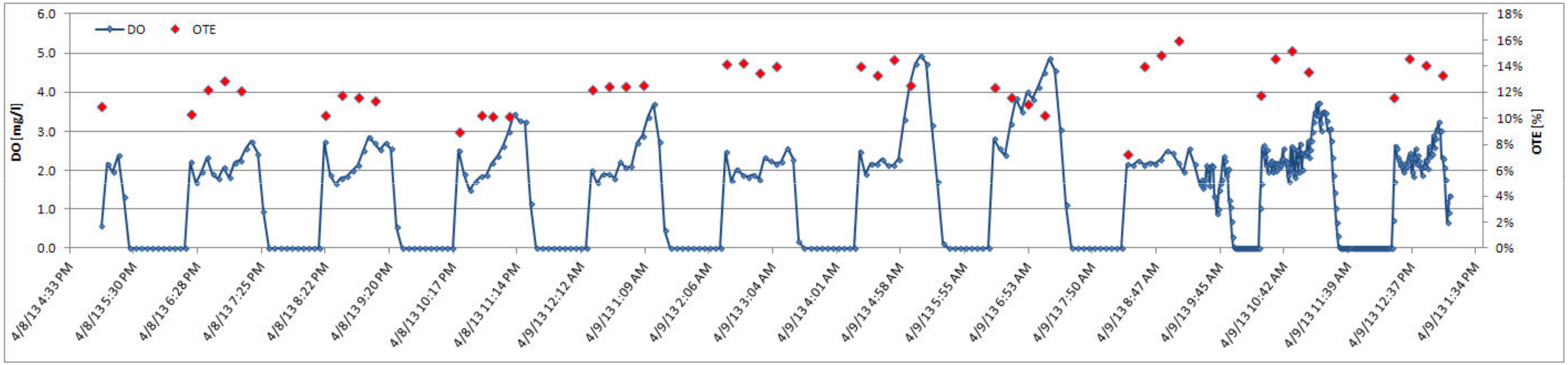


(Krampe J. et al. (2003) Water science and technology, 47(11))

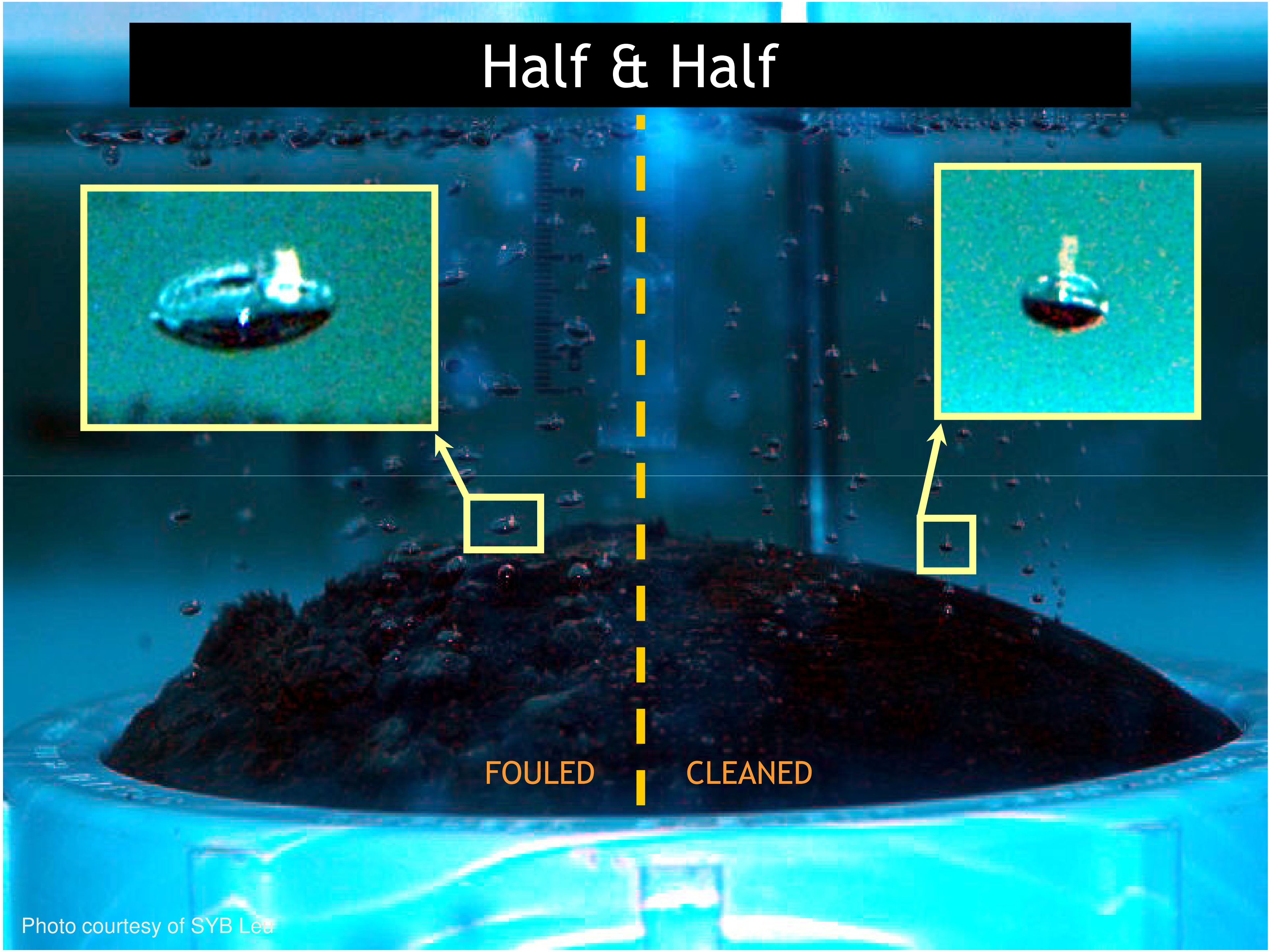
If SOTE is available, the α factor can be estimated and compared with data from other tests. E.g. in this case α estimated in our tests are compared with other data plotted vs the MLSS.

• MONITORING OF OXYGEN TRANSFER EFFICIENCY ON A DAILY BASIS:

The device is able to measure the OTE with a fixed frequency in a specific position.



The daily trend of OTE along with trend of DO concentration allow to estimate potential energy and economic savings.


Half & Half
FOULED
CLEANED
Photo courtesy of SYB Lee

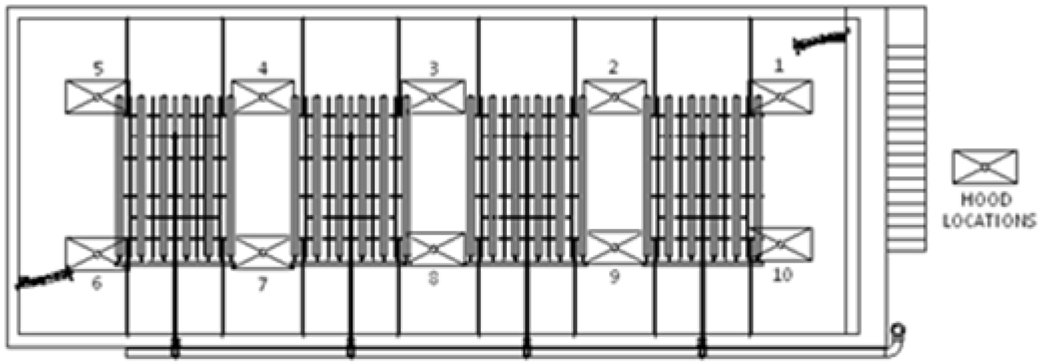
• EVALUATION OF DIFFUSERS FOULING:

Within the AERE project three off-gas tests were carried out in a small WWTP

- 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 requirement

• EVALUATION OF DIFFUSERS FOULING:

Test	Conditions of the diffusers	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

- 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

• EVALUATION OF DIFFUSERS FOULING:

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:

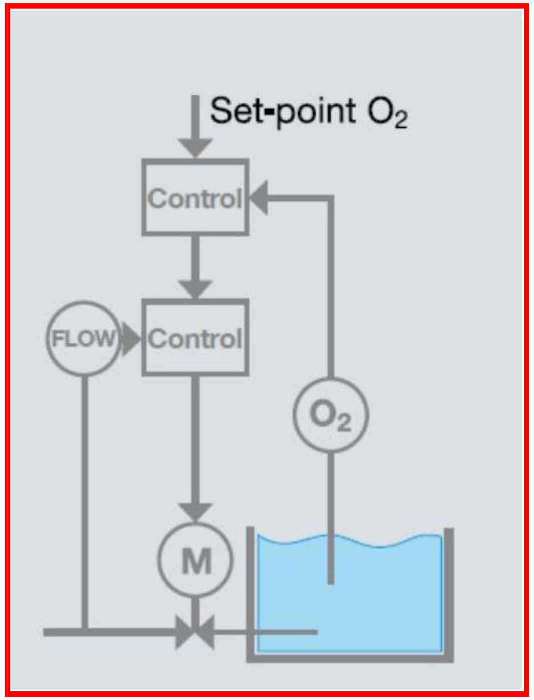
Test	αSOTE (%)	Air flowrate* (Nm^3/h)	Energy consumption (kWh/year)	$\frac{kWh}{COD_{rem}}$	Aeration costs (€/years)	$\frac{€}{COD_{rem}}$
June 2010	18.0	290	42048	0.65	6307	**0.10**
May 2012	9.5	545	71832	1.11	10774	**0.17**
July 2012	**15.8**	**330**	**43800**	**0.68**	**6570**	**0.10**

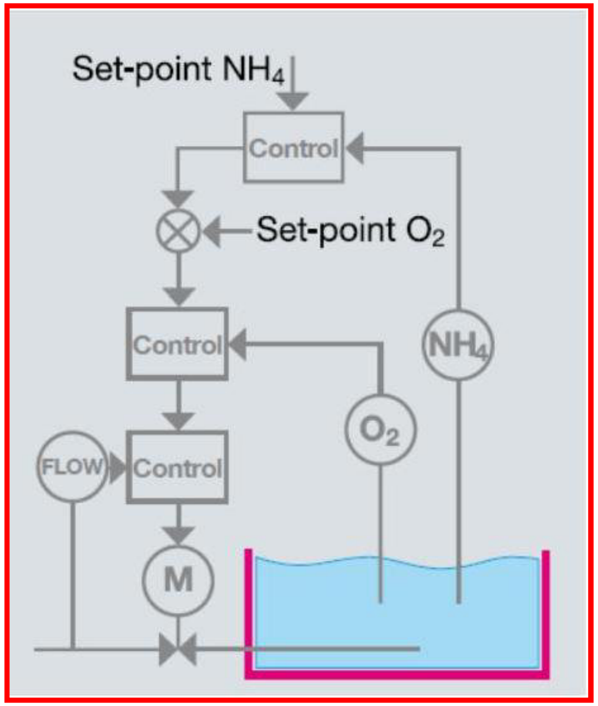
* Air flow necessary to guarantee an SOTR=26kgO_2/h assuming 0.55 as α-value

- A reduction in the αSOTE value makes an increase in management costs by approximately 4500€/y
- The maintenance operation allowed to reduce 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.

OPTIMAL MANAGEMENT OF AIR FLOW RATE:

This system have been set-up in a large WWTP (600.000 p.e.).

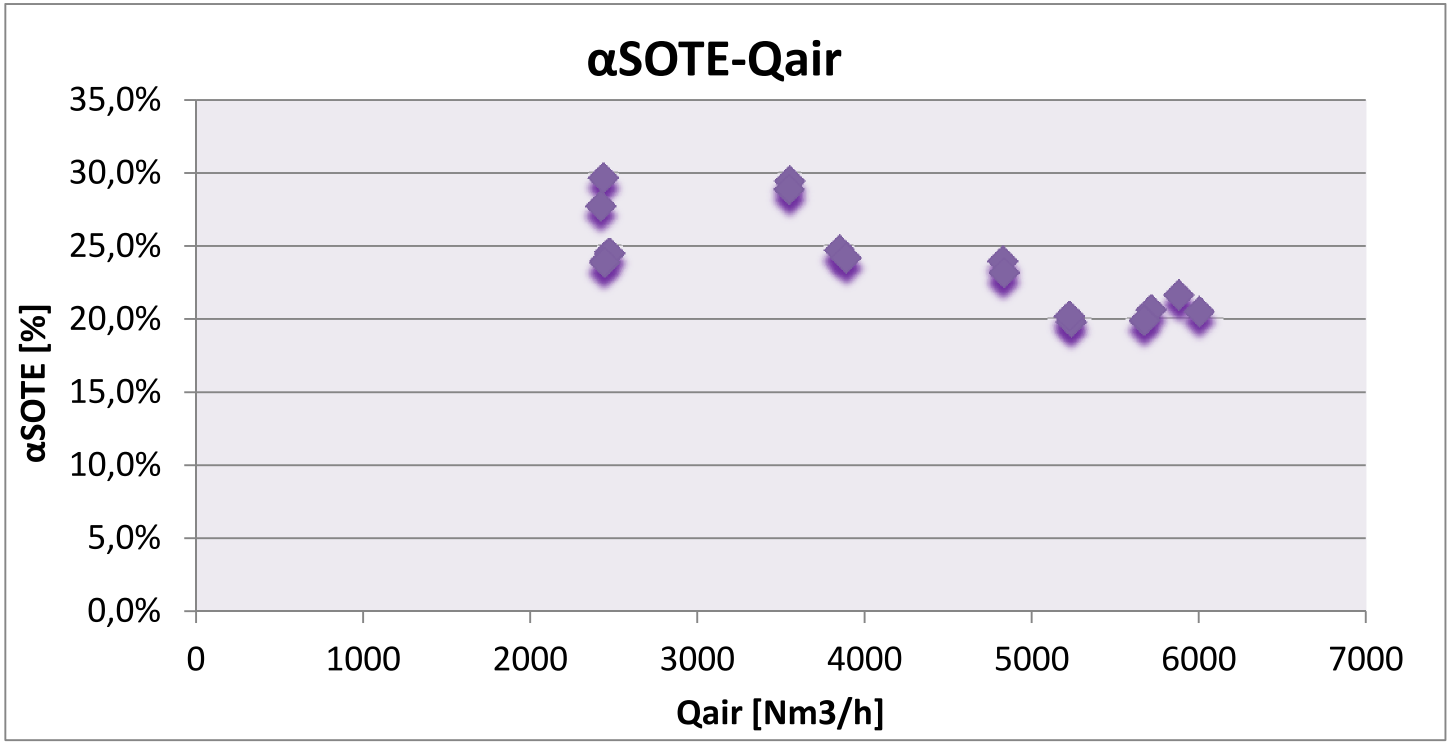




FIRST TEST:
Flow rate management was based on DO in the tank.

SECOND TEST:
Air flow rate management was based on di N-NH_4 in the effluent

• EVALUATE THE RELATION BEWTEEN TRANSFER EFFICINCY AND AIR FLOW RATE



This relation is needed to evaluate the effect of advanced air flow rate regulation systems on aeration costs.

OPTIMAL MANAGEMENT OF AIR FLOW RATE:

The change of the air flow rate controller allowed to increase the *aeration efficiency*:

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

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

DO ↓ ⇨ AE ↑

In the case study, an improvment of **10%** of the mean OTE on a yearly based can allow to save about **500MWh/y (75000 €/y)**

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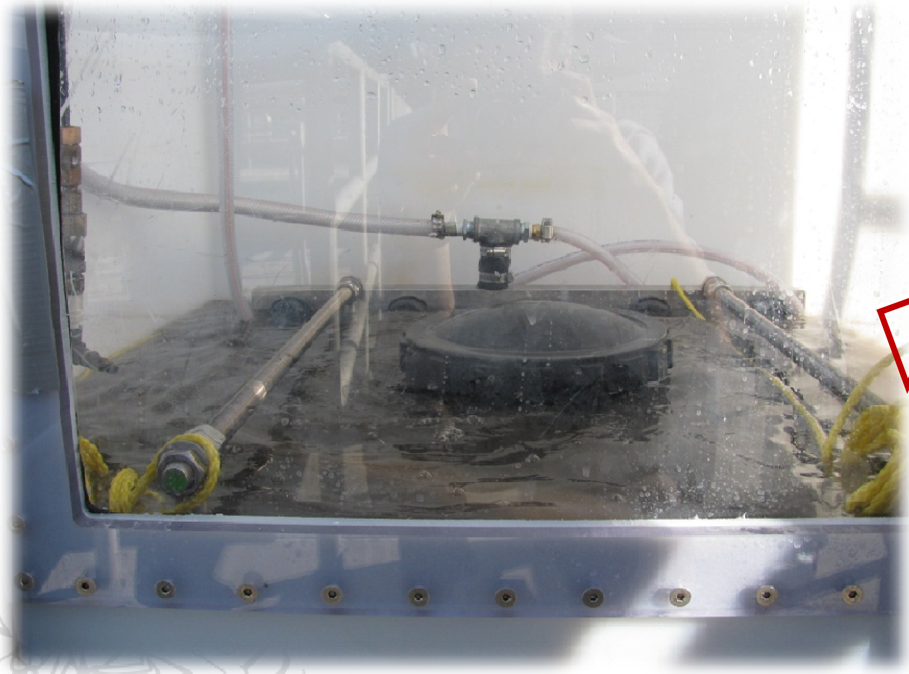
SUPPORT FOR DESIGN

- Compare the efficiency transfer of different (clean) diffusers
- Monitoring the efficiency decay of diffusers during the time.



Thank you for your attention!

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