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OF THE 2012
M&R SEMINAR SERIES

BEFORE WE BEGIN

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- QUESTION AND ANSWER SESSION WILL FOLLOW PRESENTATION
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Engineers Without Borders – UCLA, UCI, LA, and OC chapters (2004 – present)

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Education : M.S. equivalent, University of Padua, Italy, Chemical Engineering *Laurea*

M.S. / Ph.D. University of California, Los Angeles , Environmental Engineering,

***Professional*:** American Academy of Environmental Engineers,

Water Environment Federation,

International Water Association,

Association of Environmental Engineering and Science Professors,

Engineers Without Borders.

Honors &: American Academy of Environmental Engineers: Research Honor Award (2011)

OXYGEN TRANSFER IN WASTEWATER TREATMENT PROCESSES:

RESEARCH PERSPECTIVES IN THE 21ST CENTURY

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Department of Chemical Engineering and Material Science

I. EFFECTS OF WASTEWATER CONTAMINANTS ON OXYGEN TRANSFER

Terminology

OTE: Oxygen Transfer Efficiency (%)

OTR: Oxygen Transfer Rate (kg_{O2}/h)

SOTE: Standardized OTE in clean water (%)

αSOTE: Standardized OTE in process water (%)

$\alpha = \alpha SOTE/SOTE$ (water quality estimate)

F = Fouling factor = $\alpha SOTE_{old} / \alpha SOTE_{new}$

DWP = Dynamic wet pressure (diff. headloss, Pa)

Ψ = Pressure factor = DWP_{old} / DWP_{new}

α: THE MOTHER OF ALL "FUDGE" FACTORS

$$\alpha = \frac{(k_L a)_{\text{process water}}}{(k_L a)_{\text{clean water}}}$$

SOTE = Standardized Oxygen Transfer Efficiency

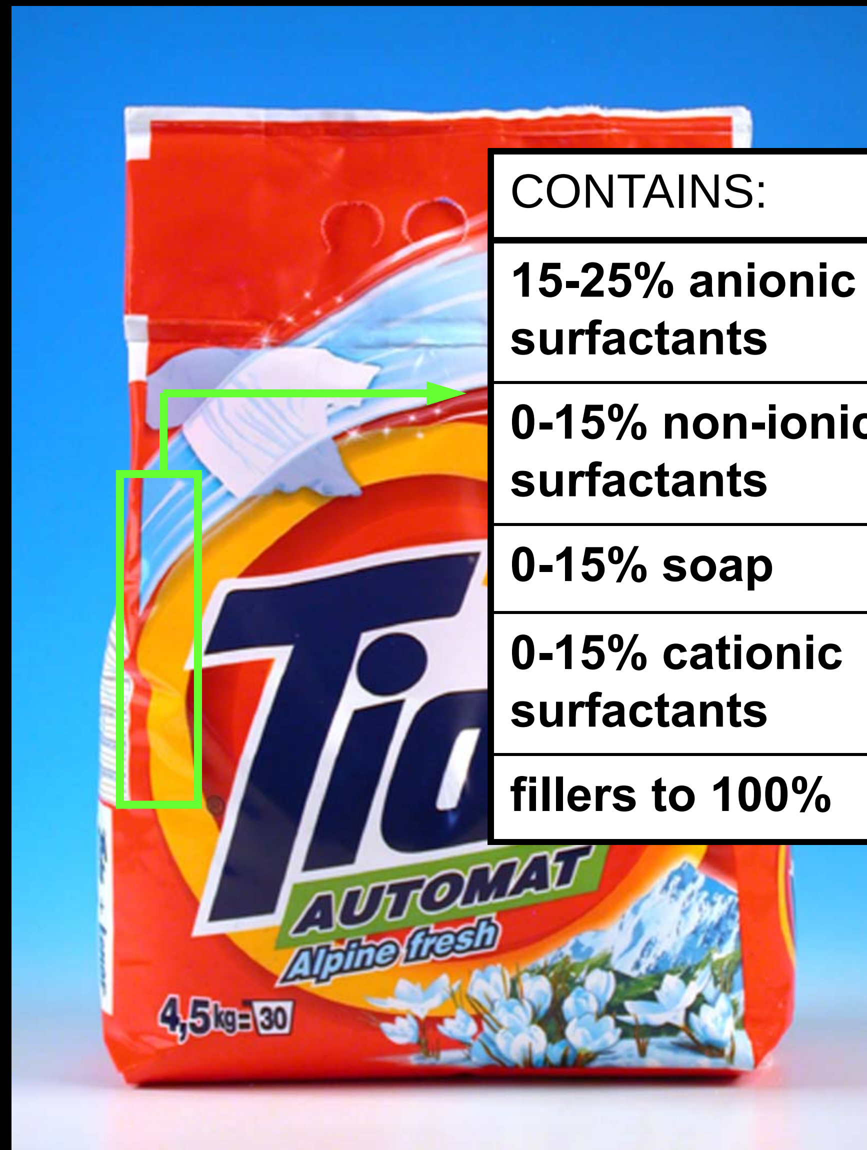
(O_2 transferred / O_2 fed)

Cost ↓ **efficiency** ↓ ↓ **trtmt requirement** ↓

$$\text{AFR} = f\,(\alpha,\ \text{SOTE},\ R_O)$$

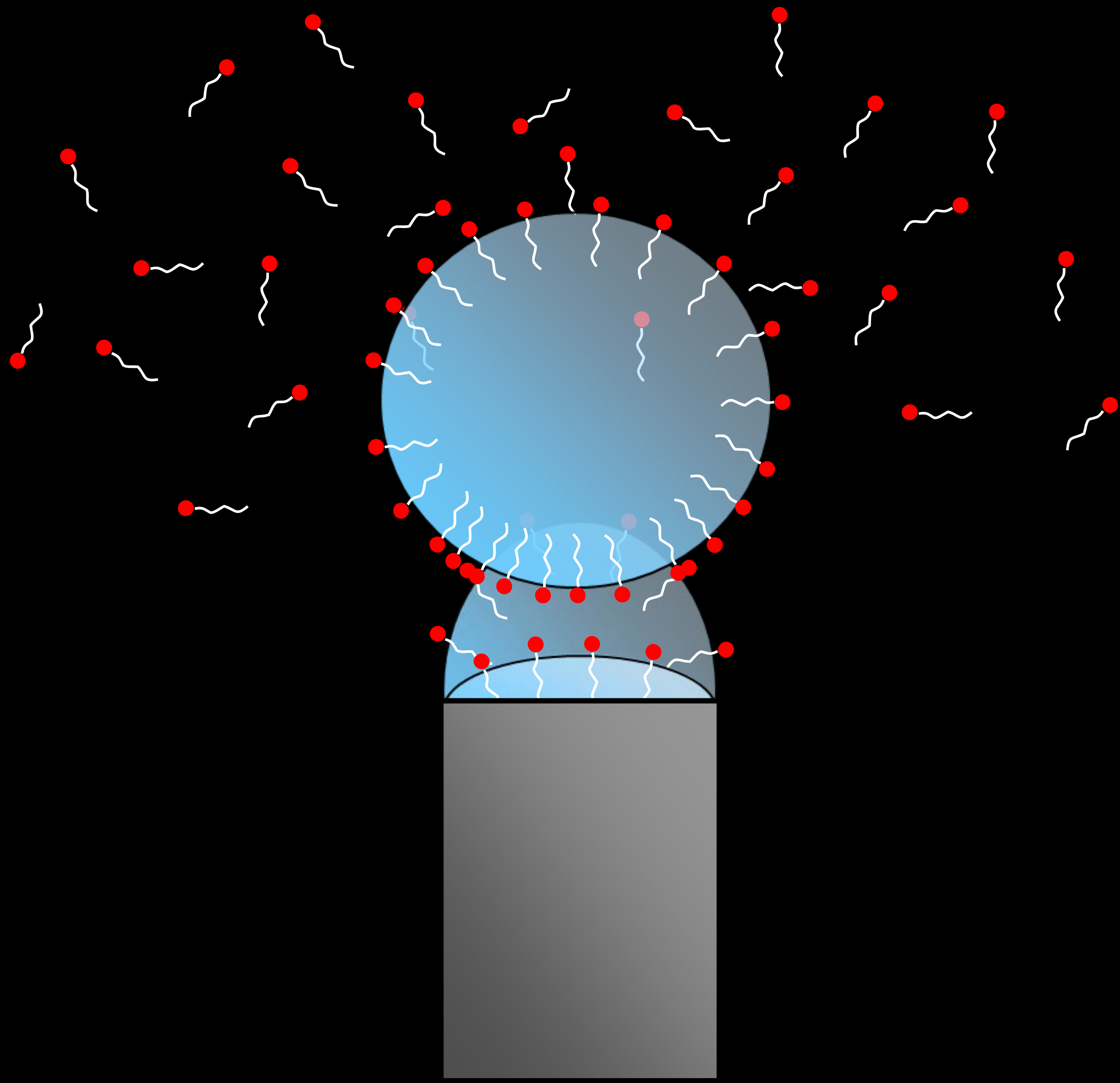
↑ **$$$** ↑ **ww** ↑ **aerator** ↑ **ww**

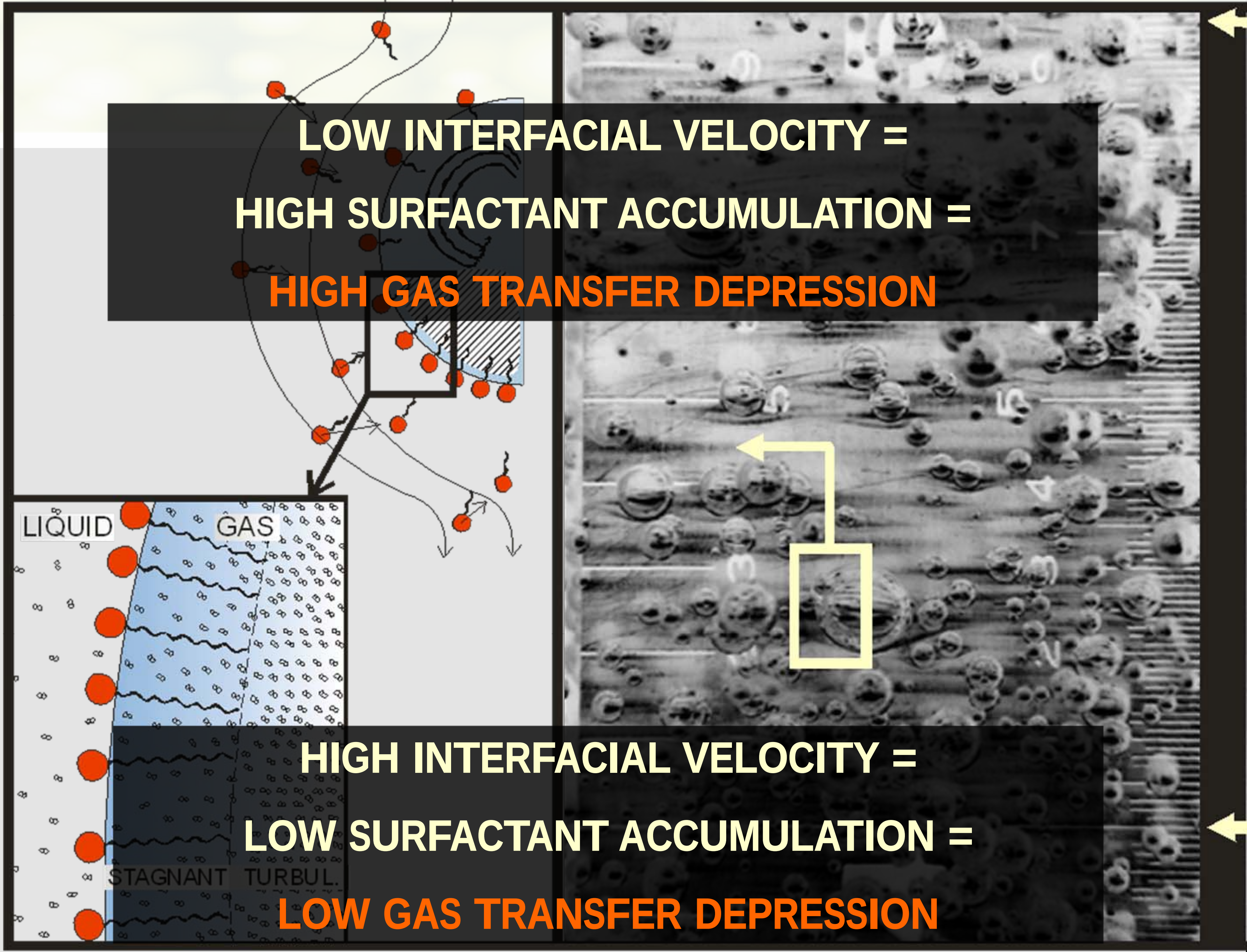
WHAT ARE THESE CONTAMINANTS?



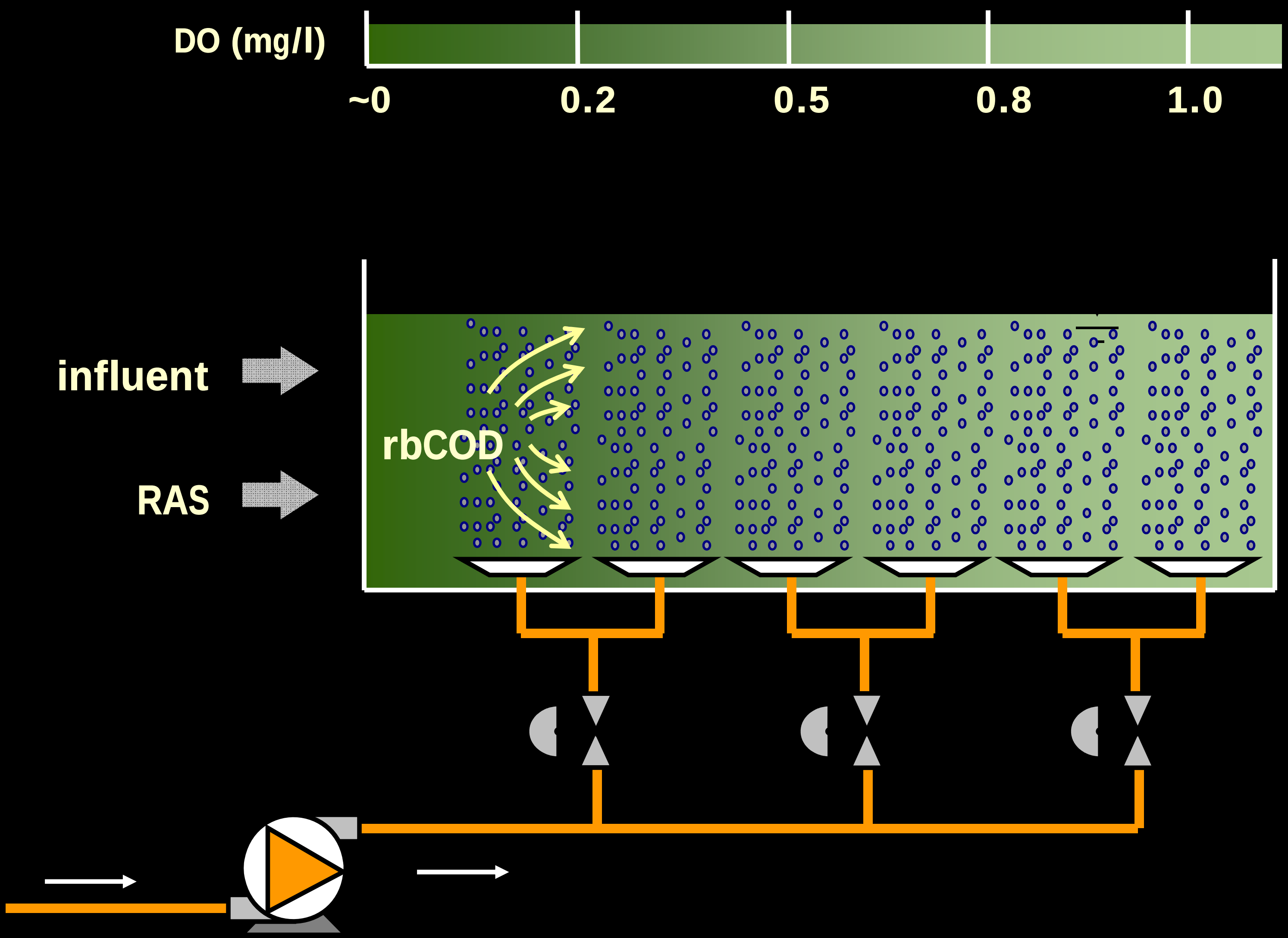
CONTAINS:
15-25% anionic surfactants
0-15% non-ionic surfactants
0-15% soap
0-15% cationic surfactants
fillers to 100%

SURFACTANT INTERFACIAL ACCUMULATION

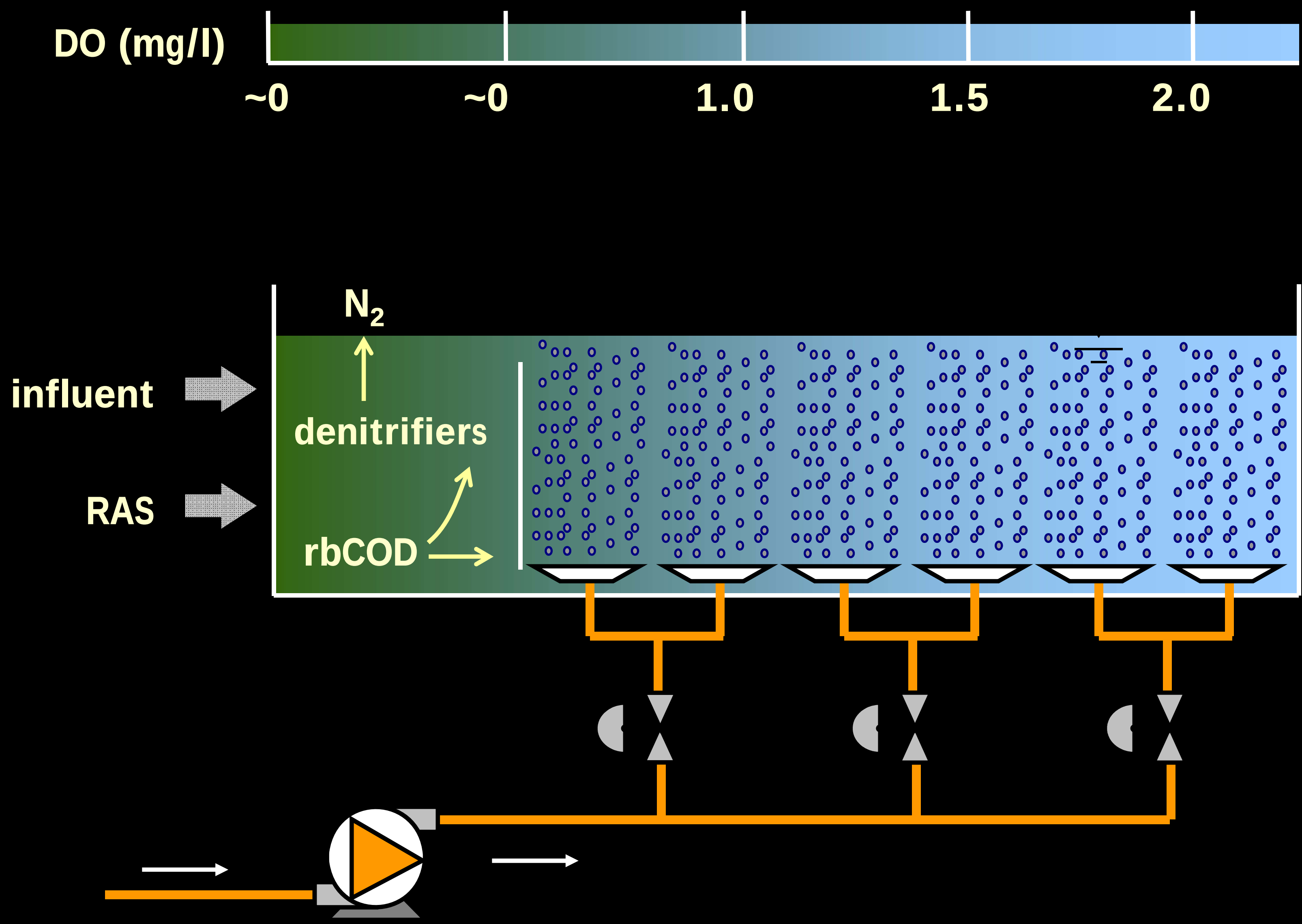



LOW INTERFACIAL VELOCITY =
HIGH SURFACTANT ACCUMULATION =
HIGH GAS TRANSFER DEPRESSION
LIQUID
GAS
STAGNANT
TURBUL.
HIGH INTERFACIAL VELOCITY =
LOW SURFACTANT ACCUMULATION =
LOW GAS TRANSFER DEPRESSION

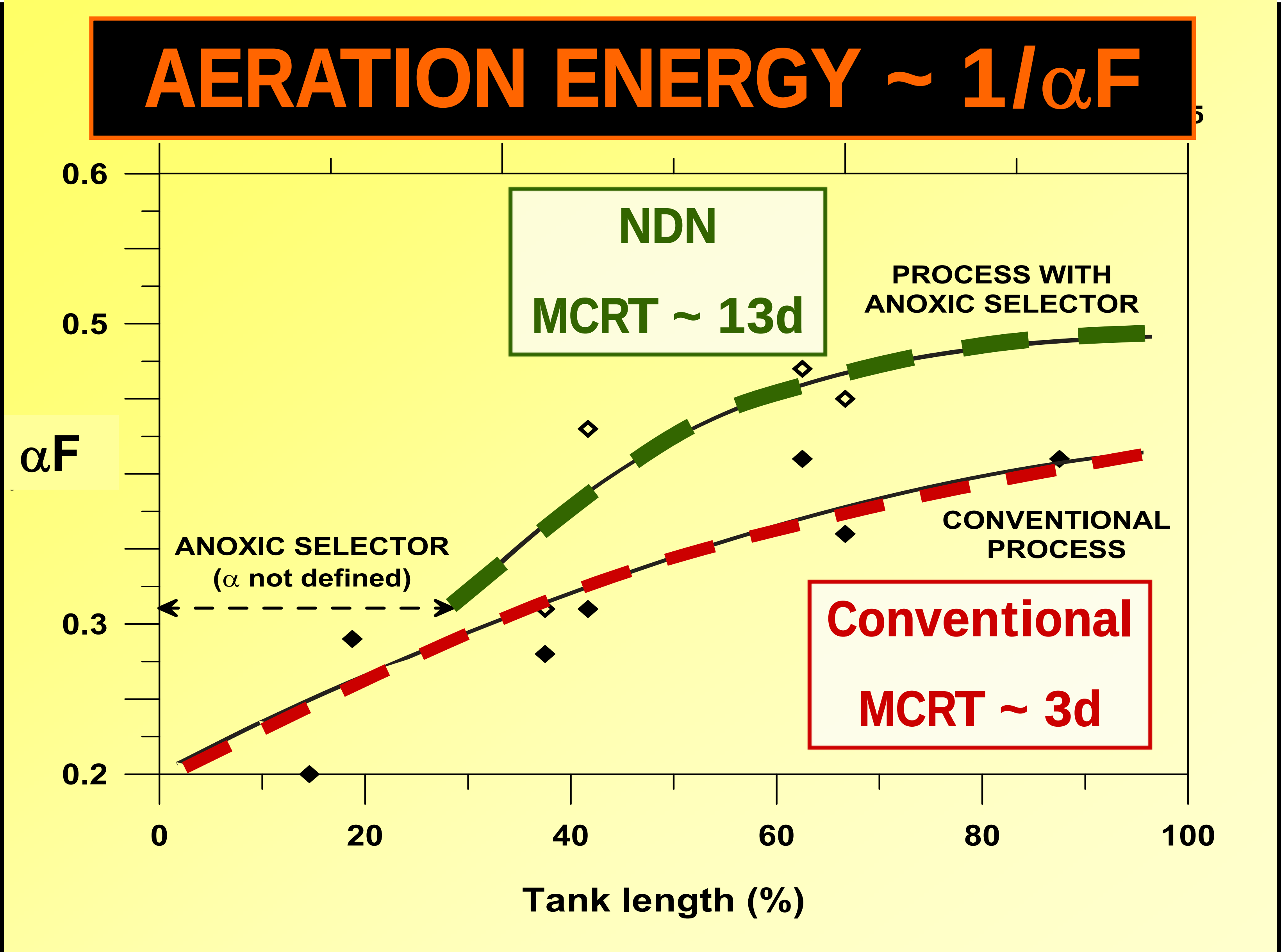
CONVENTIONAL LAYOUT



NDN LAYOUT



Alpha: Conventional vs. NDN



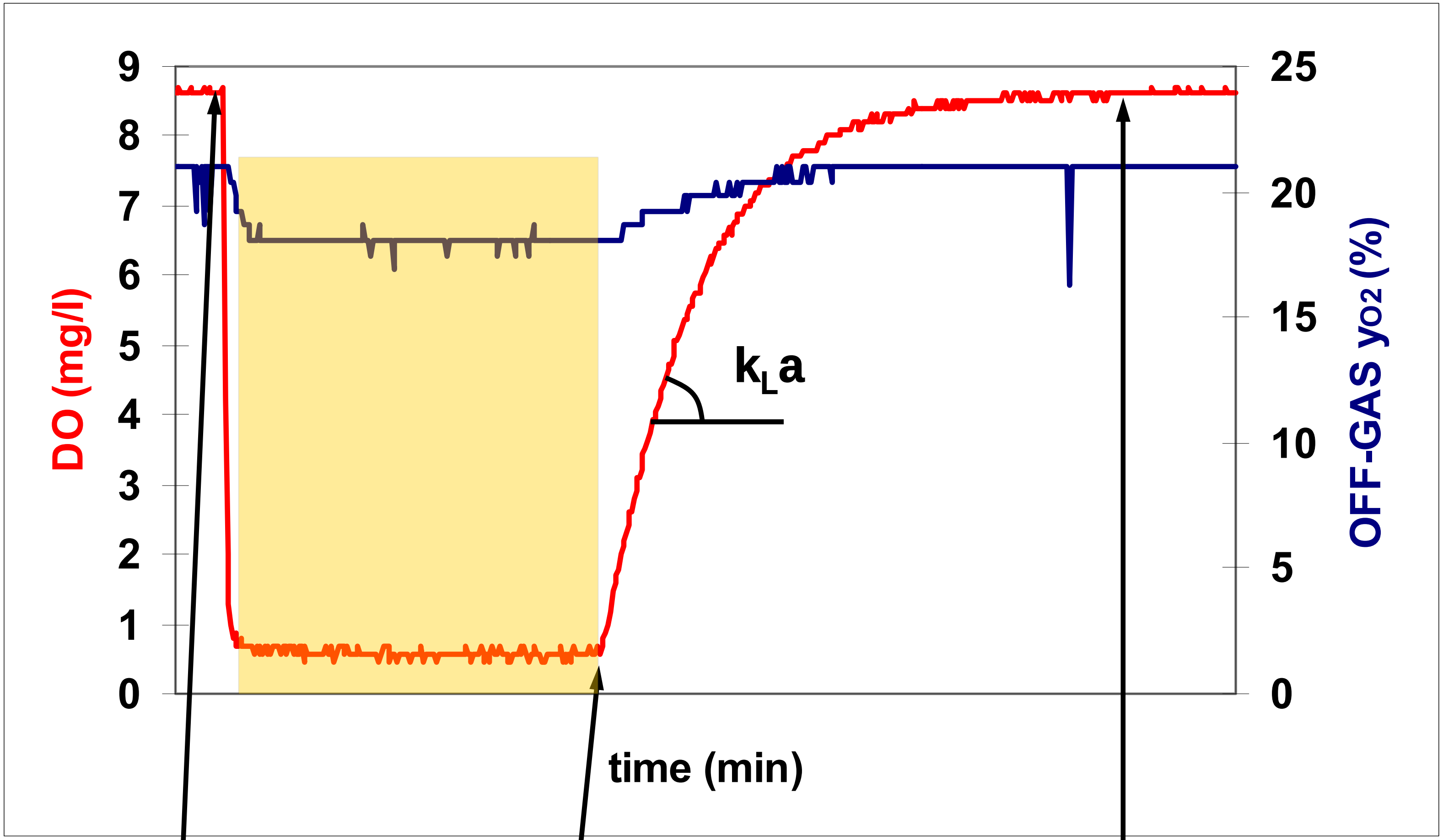
II. MEASUREMENT OF OXYGEN TRANSFER IN CLEAN WATER

Lab-scale aeration tank

Dimensions: 3 x 3 x 5 ft

Submergence: 4 ft

Clean Water Test results



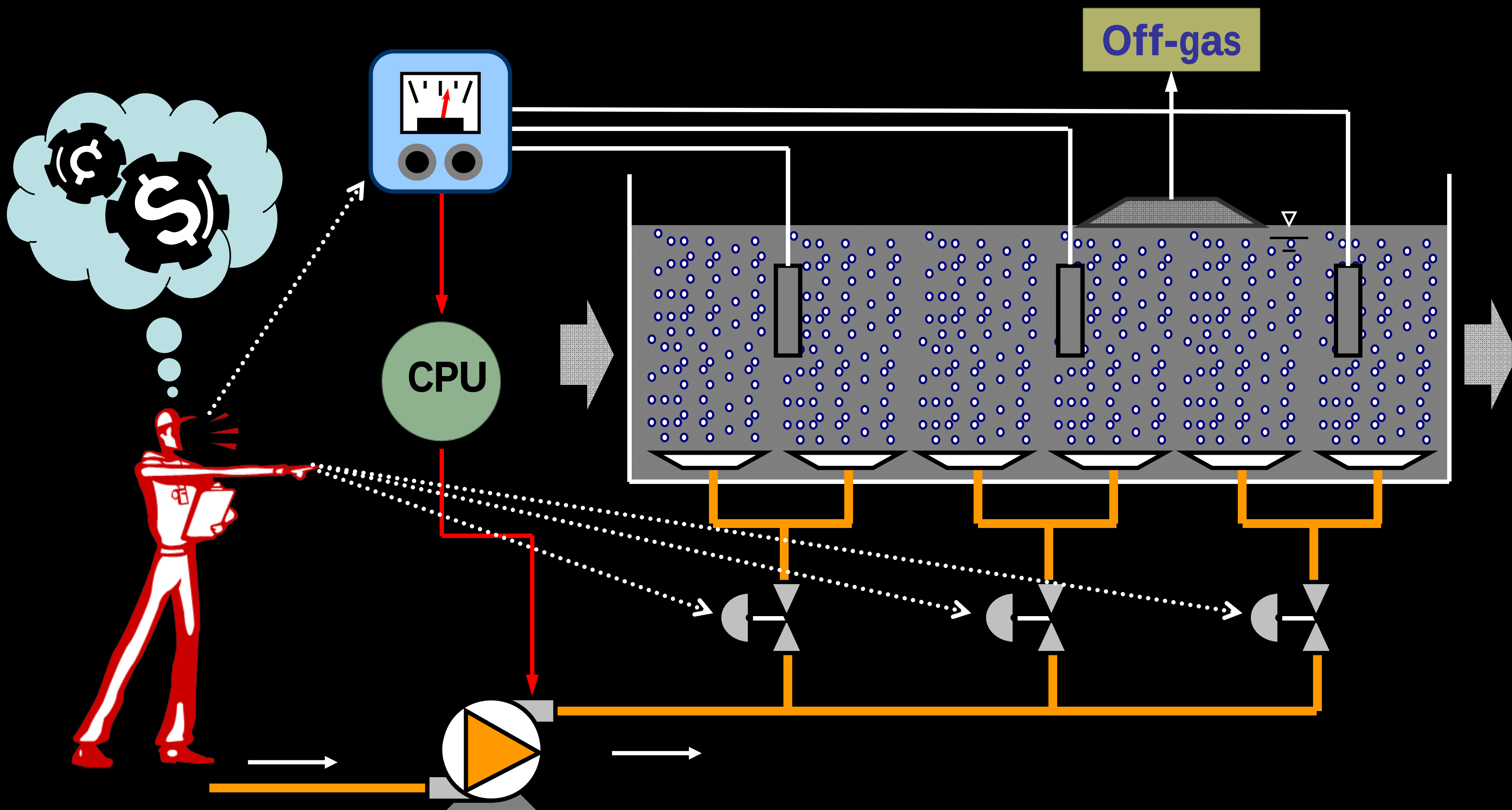
Na_2SO_3 added

O_2 scavenging completed

C_{sat} is reached

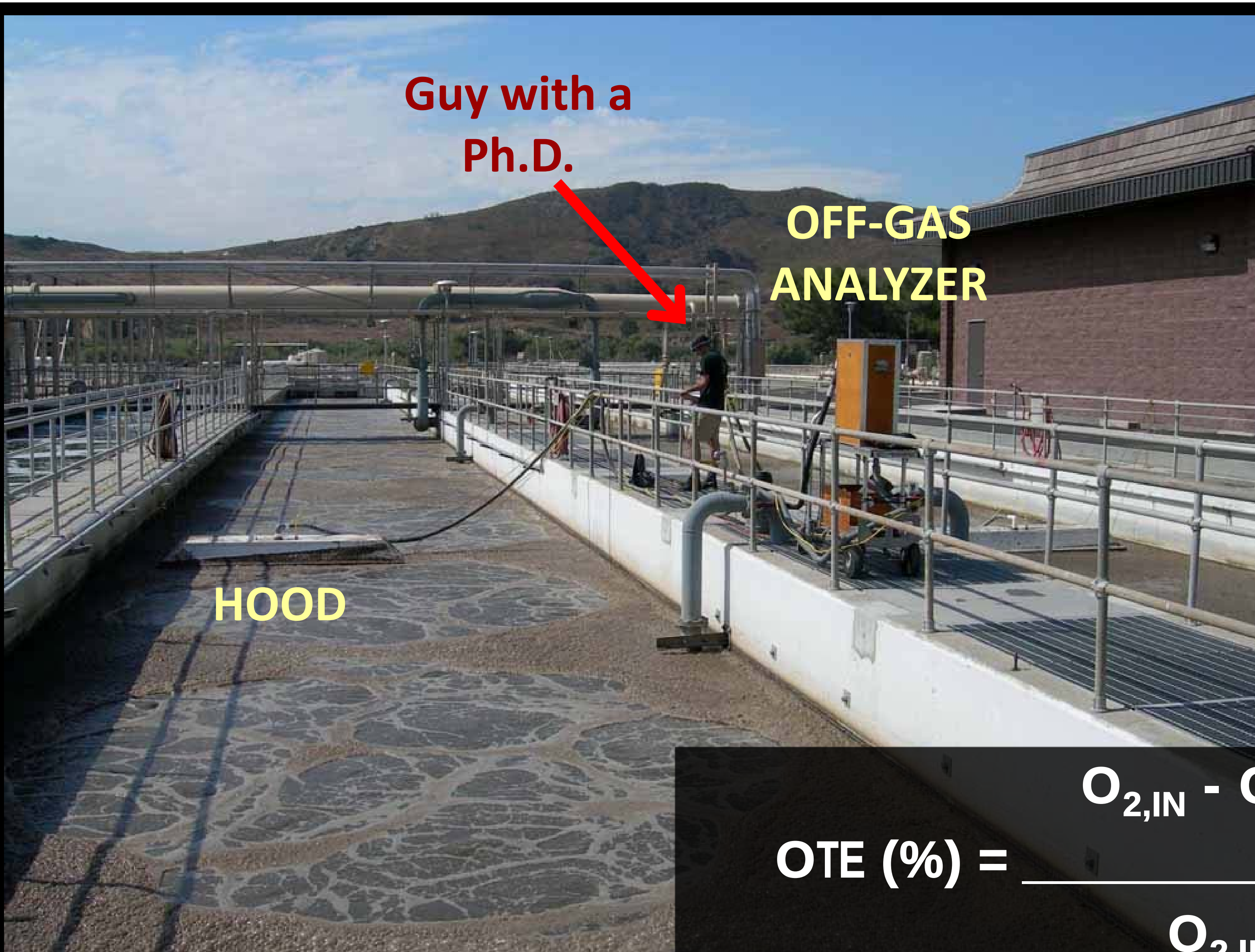
III. FIELD MEASUREMENTS OF OXYGEN TRANSFER IN WASTEWATER

AERATION EFFICIENCY TESTING



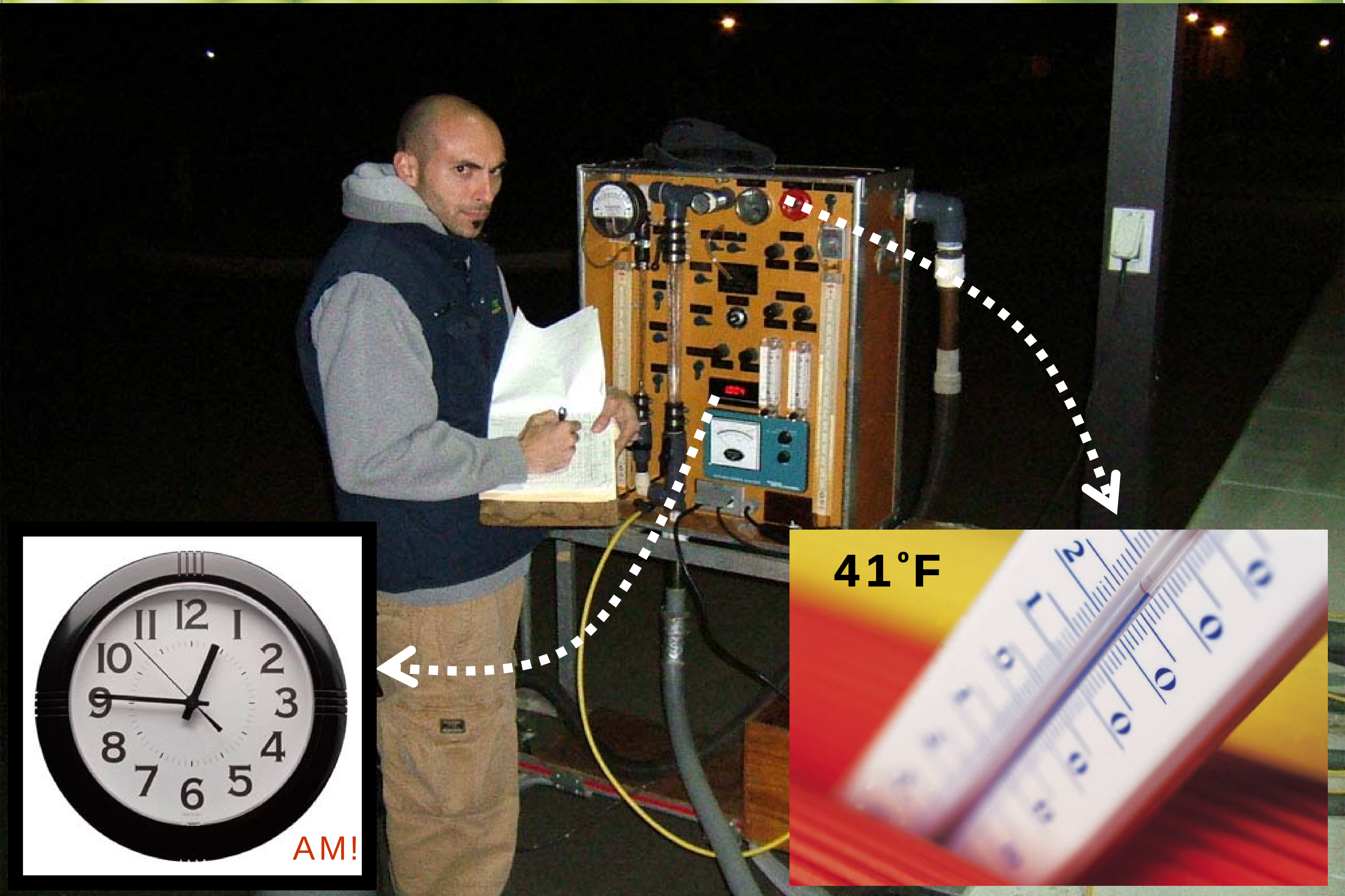
$$OTR = (k_L a \cdot V)\,[C_{sat} - (DO_{exc} + DO_{needed})] = kg_{O_2}/d = \$\$\$/d$$

TRADITIONAL OFF-GAS TESTING SETUP



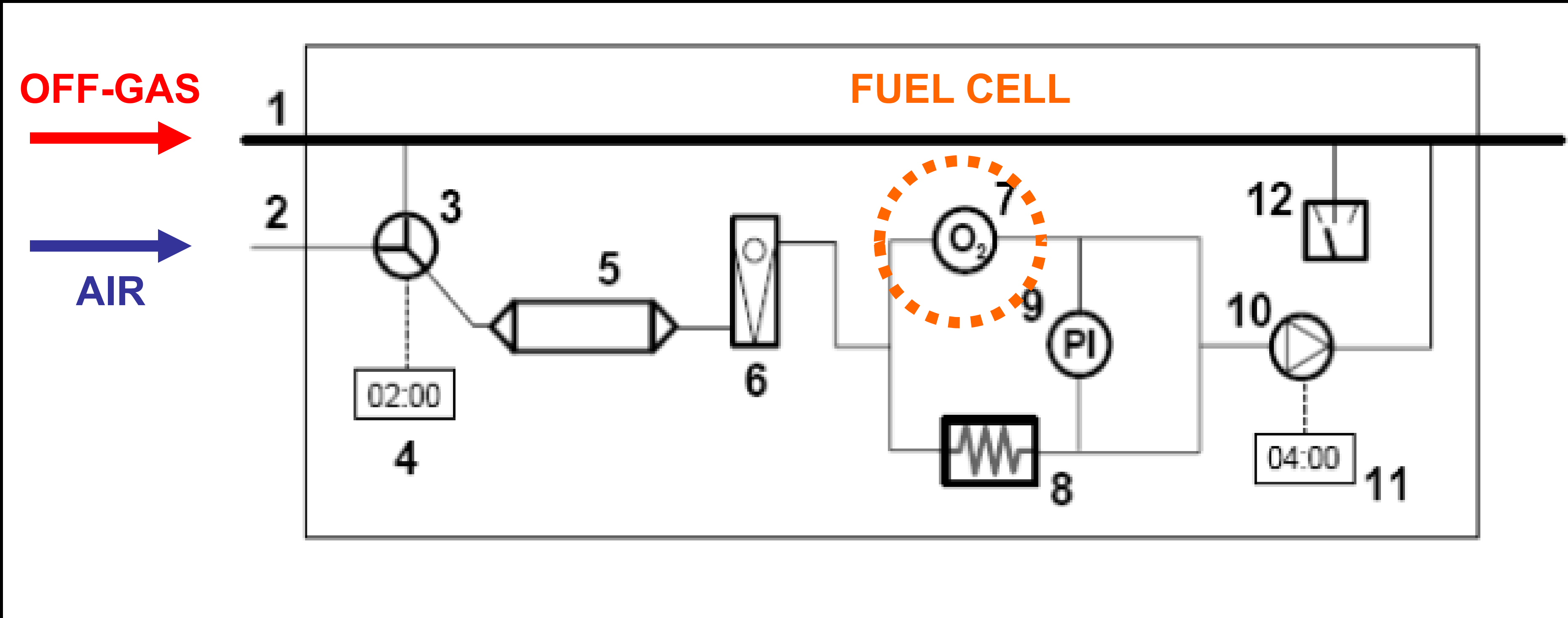
$$OTE\,(\%) = \frac{O_{2,IN} - O_{2,OUT}}{O_{2,IN}}$$

PITFALLS OF TESTING…



CURRENT OFF-GAS SETUP

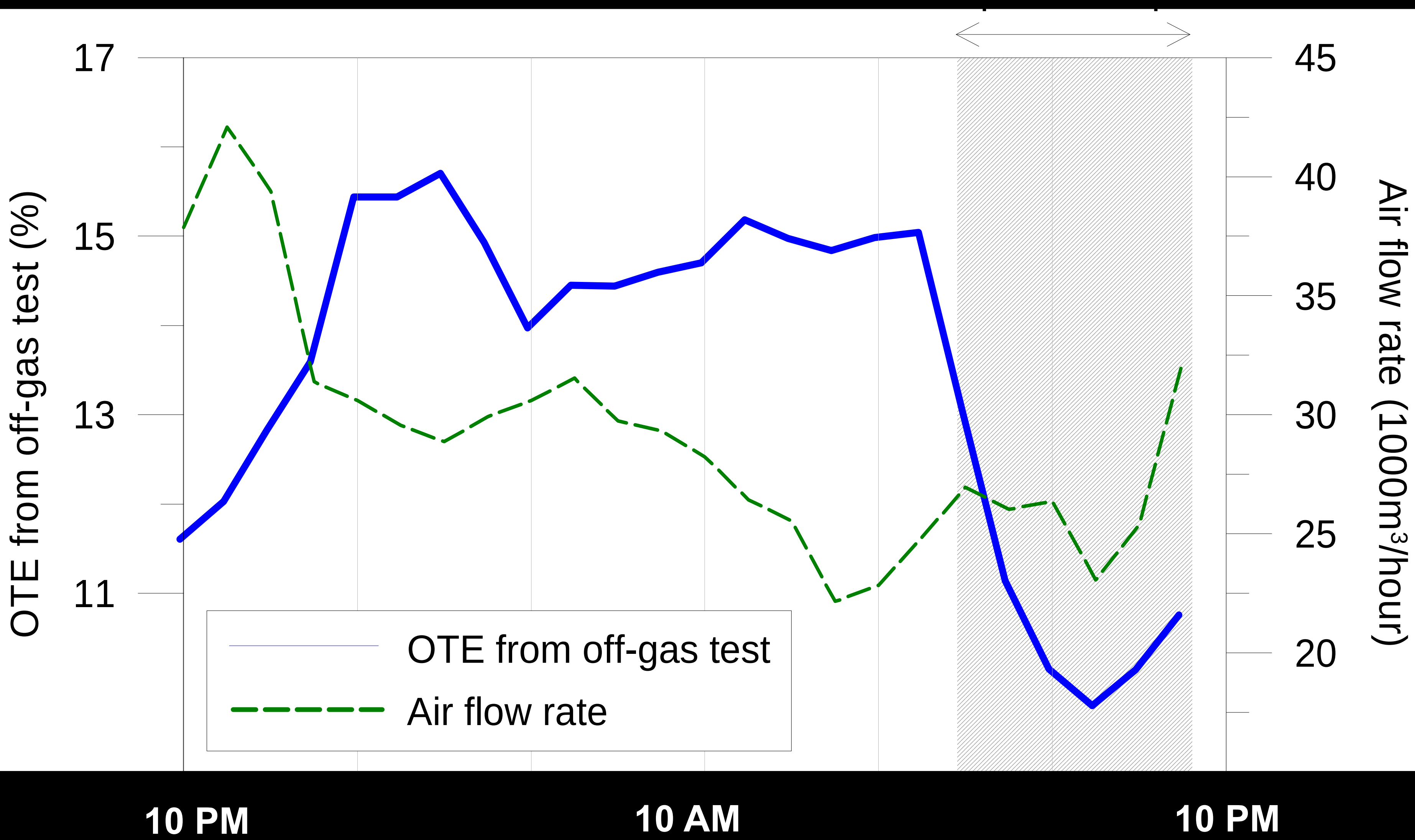
Schematic of automated analyzer



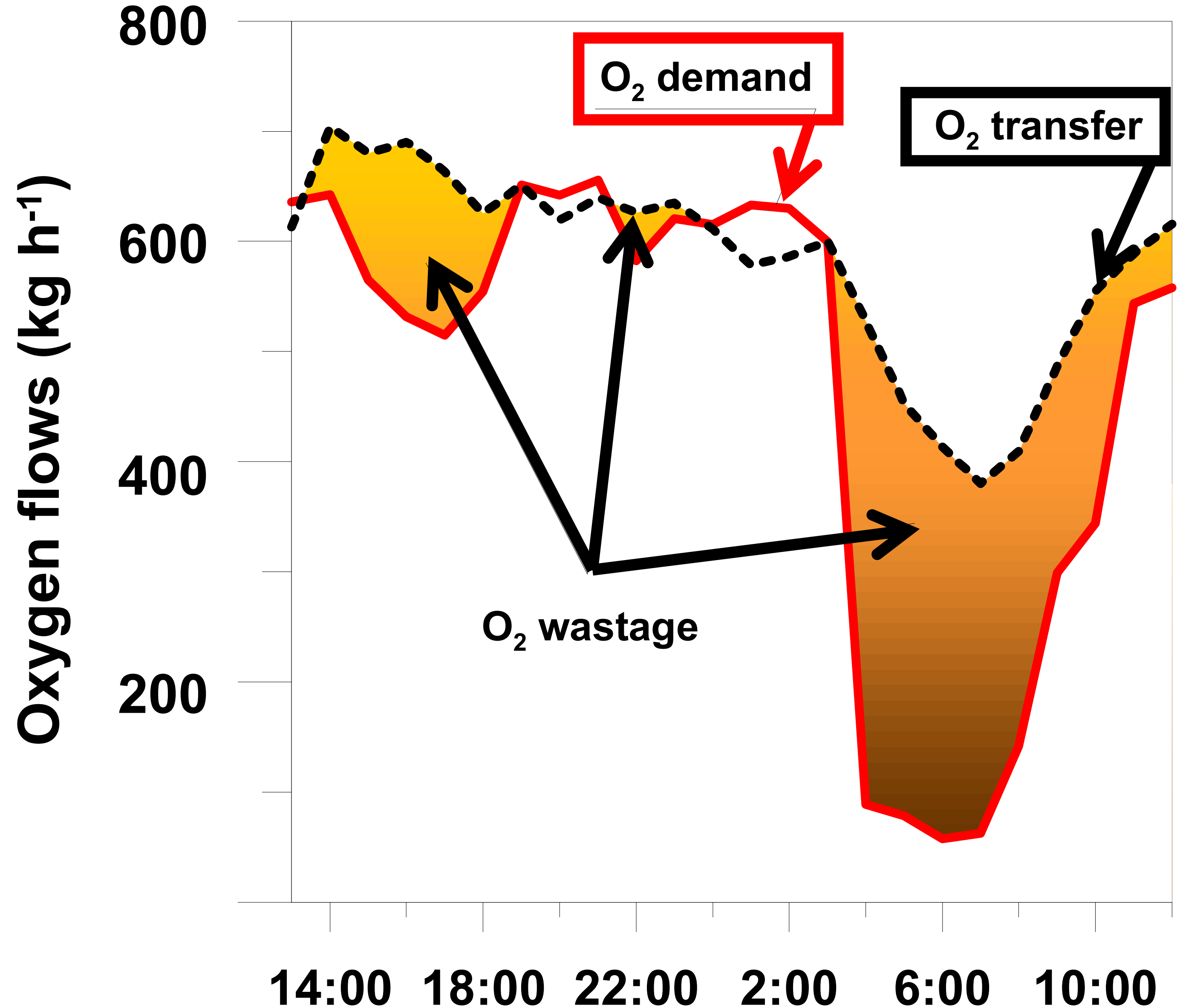
Key: 1) off-gas hose (from collection hood); 2) reference air intake; 3) three-way valve; 4) time delay relay; 5) column for CO_2 and H_2O removal; 6) flow meter; 7) oxygen fuel cell; 8) resistance; 9) differential manometer; 10) vacuum pump; 11) time delay relay; 12) air velocity meter. Solid lines = hydraulic line, dashed lines = electrical connection

REAL-TIME OFF-GAS ANALYSIS

24hr MONITORING

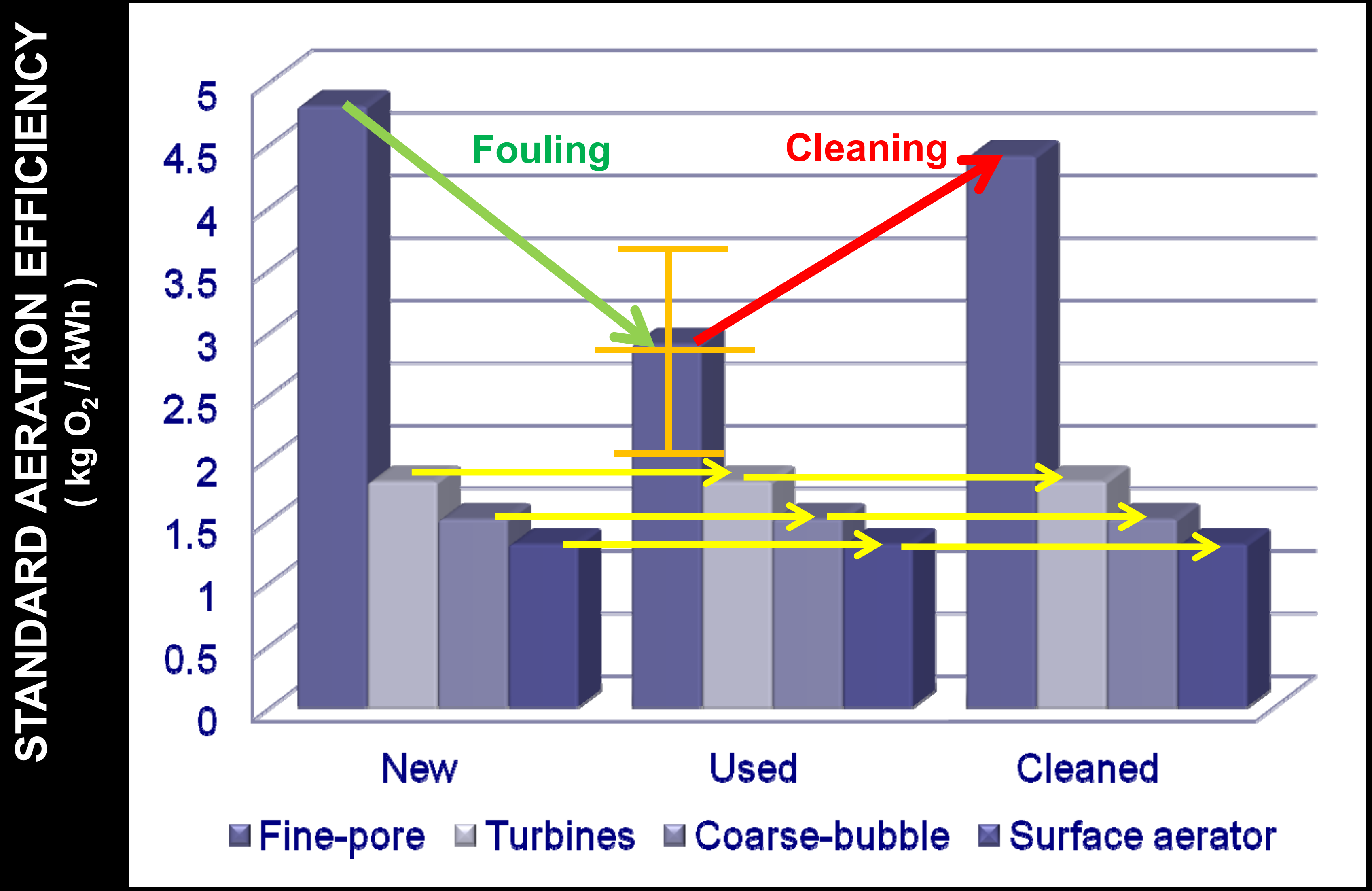


24 hrs – PLANT OPERATIONS



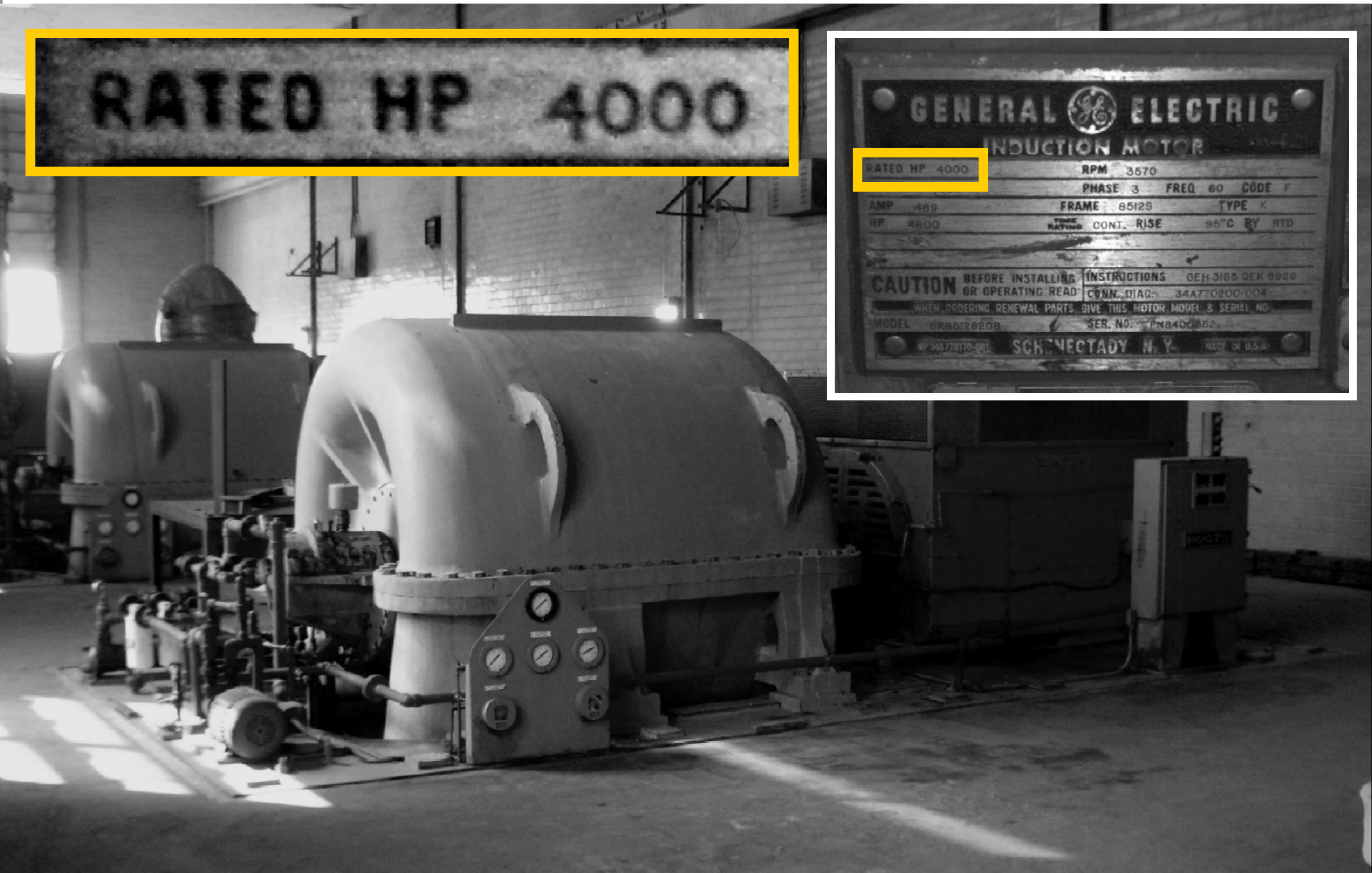
IV. LONG-TERM DIFFUSER FOULING

Aeration Efficiency over time

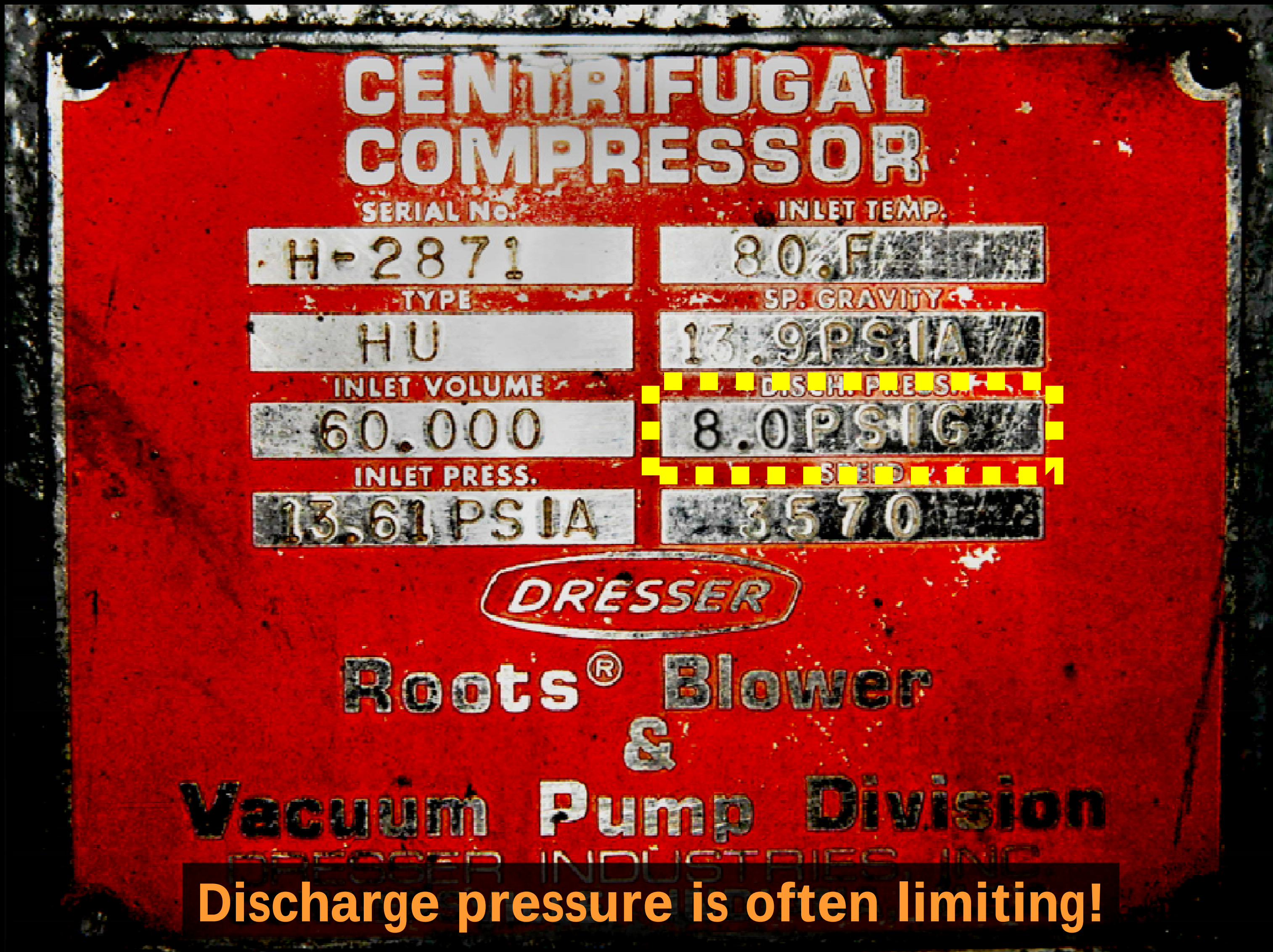


After Stenstrom and Rosso (2008)

Big challenges



Blower limits

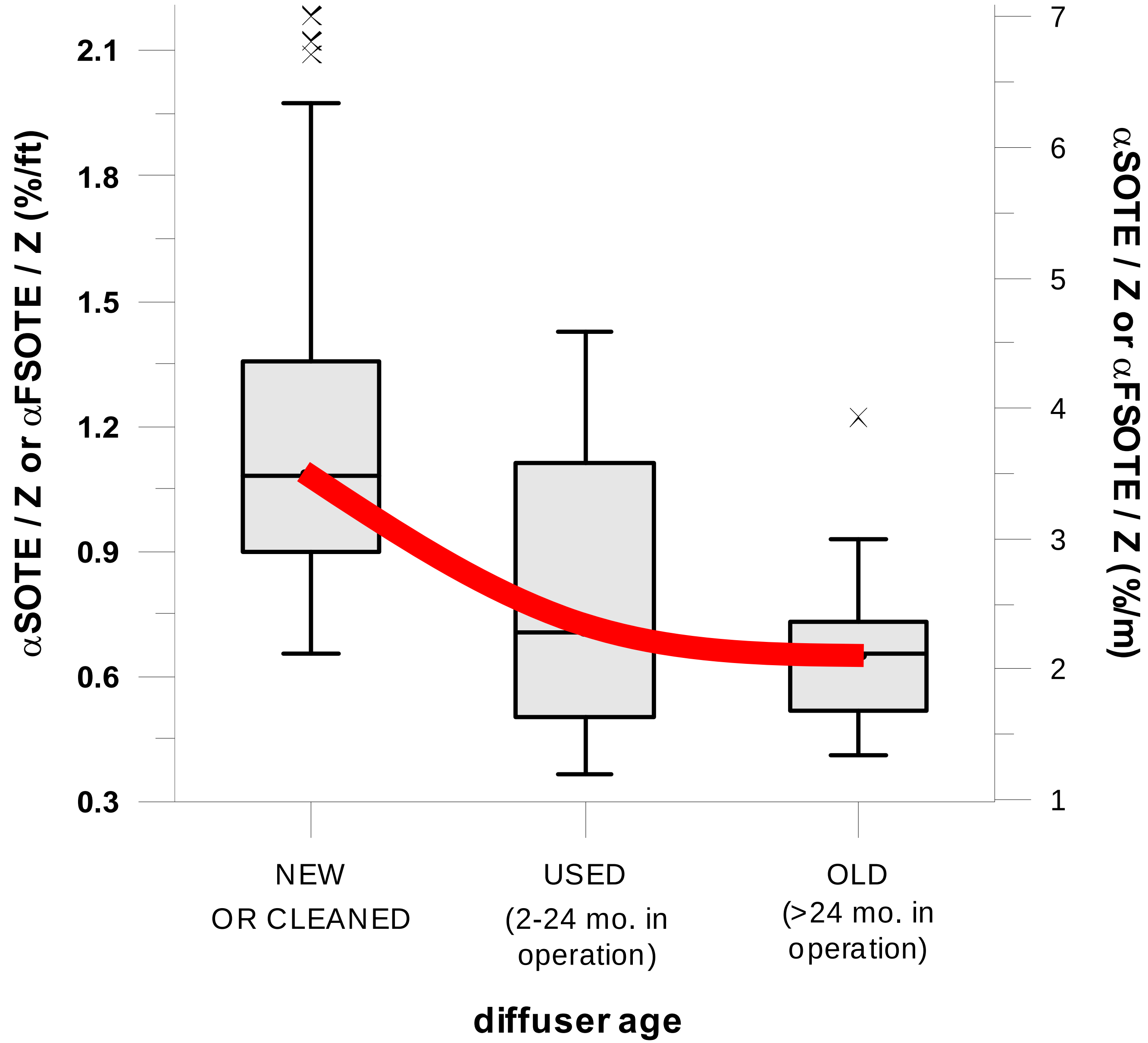


Discharge pressure is often limiting!

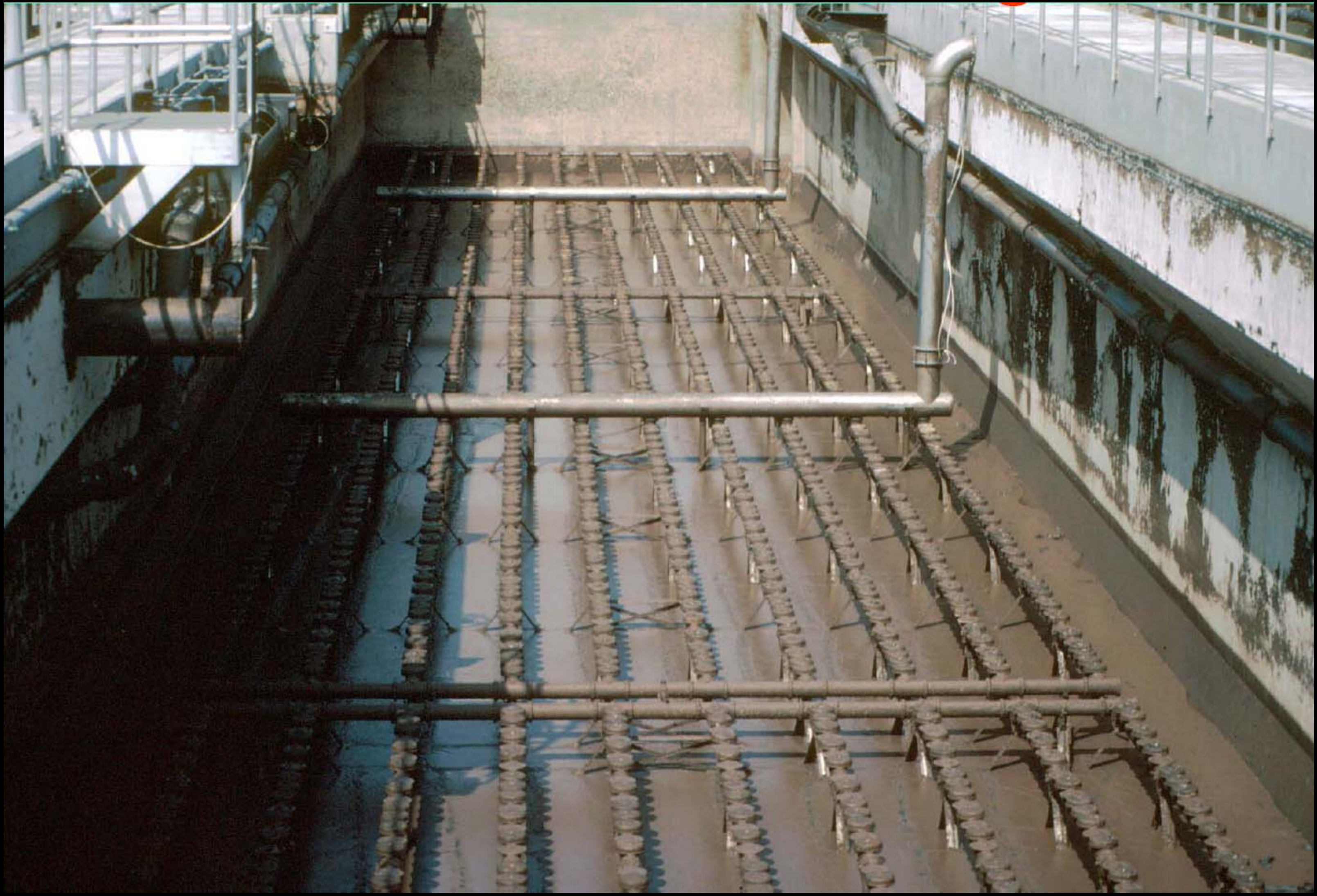
Blowers rule

BLOWERS DO NOT COMPRESS AIR,
THEY BLOW IT.

Plant histories of efficiency: ⟨SOTE

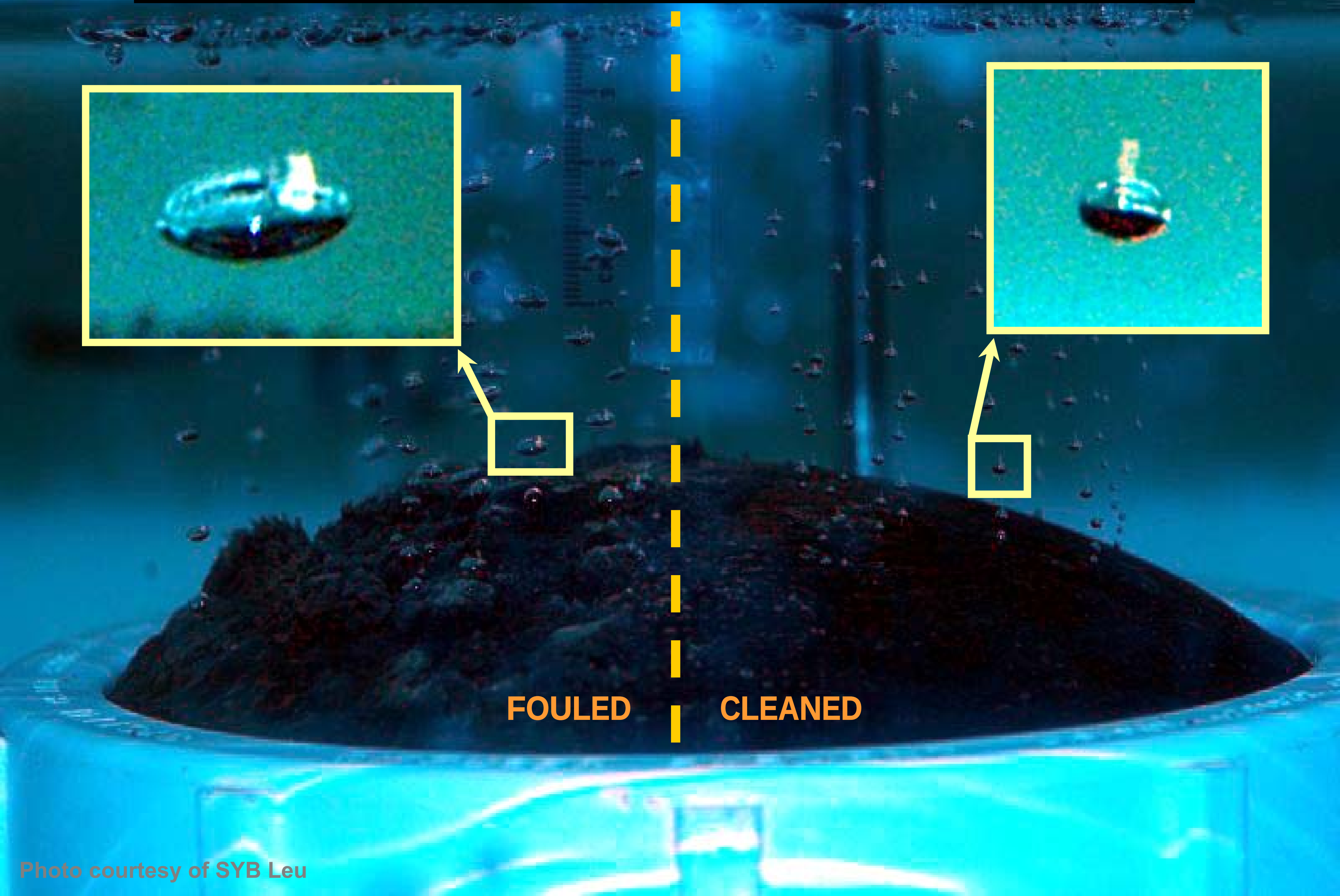


Pre-cleaning

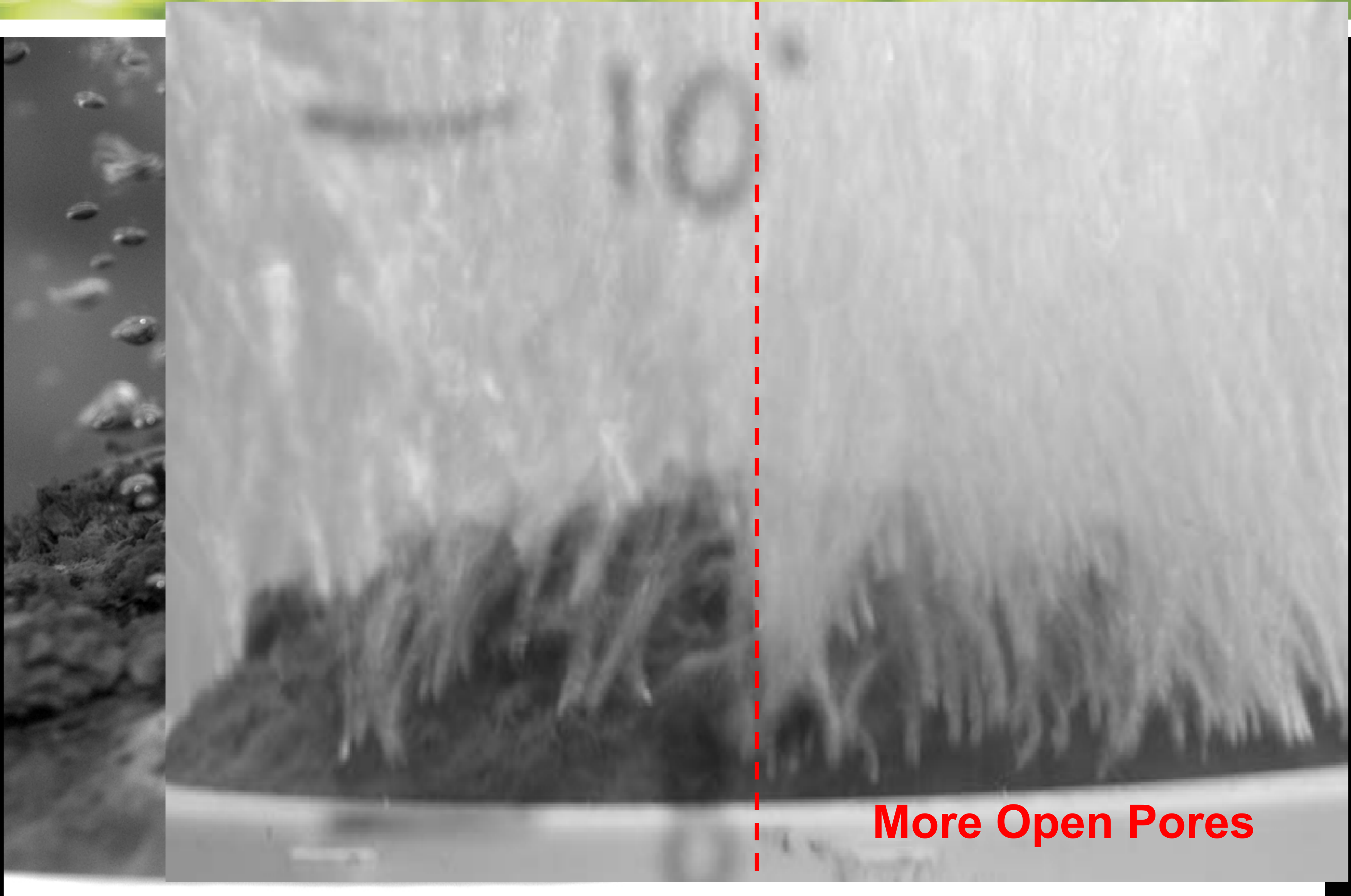


Post-cleaning

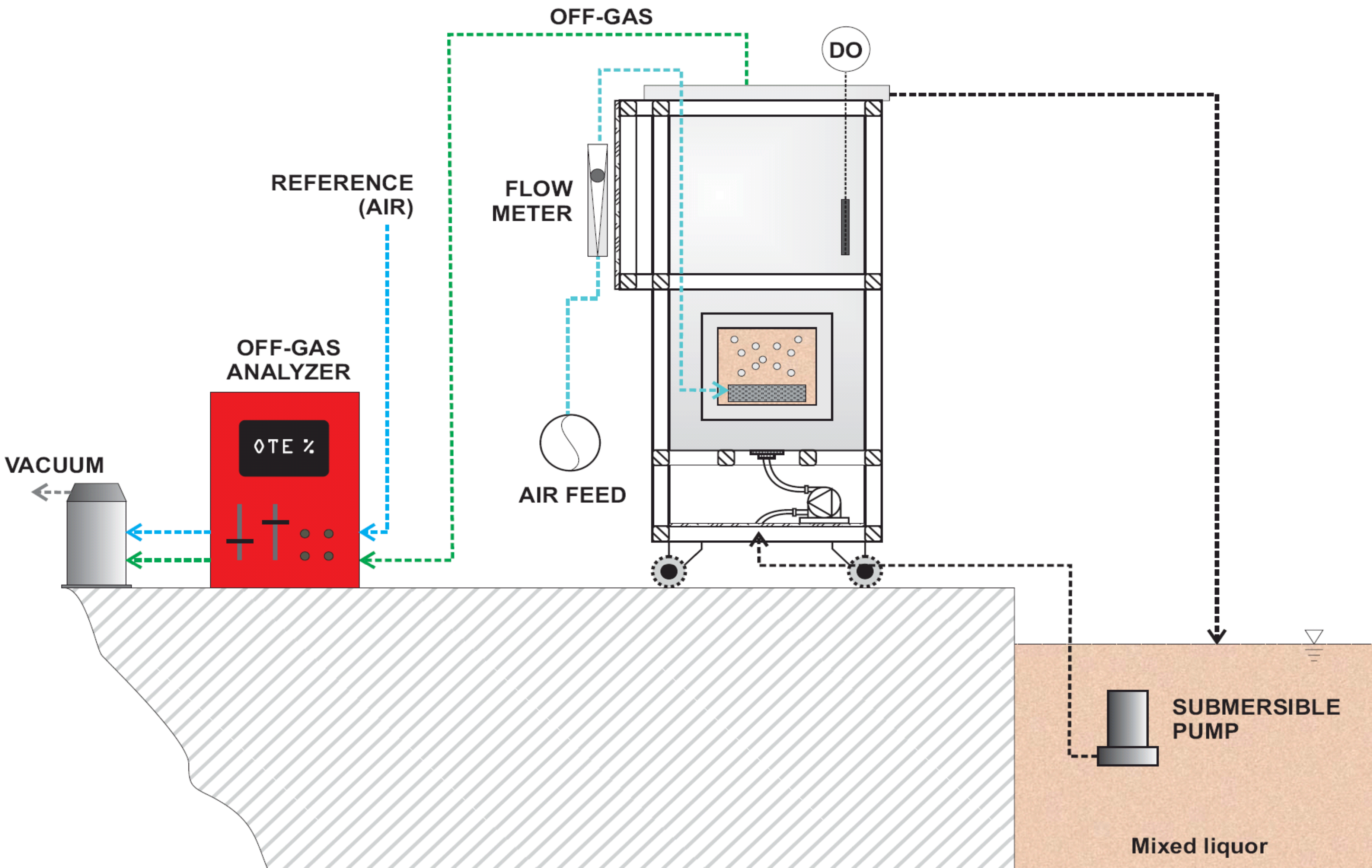
Half & Half



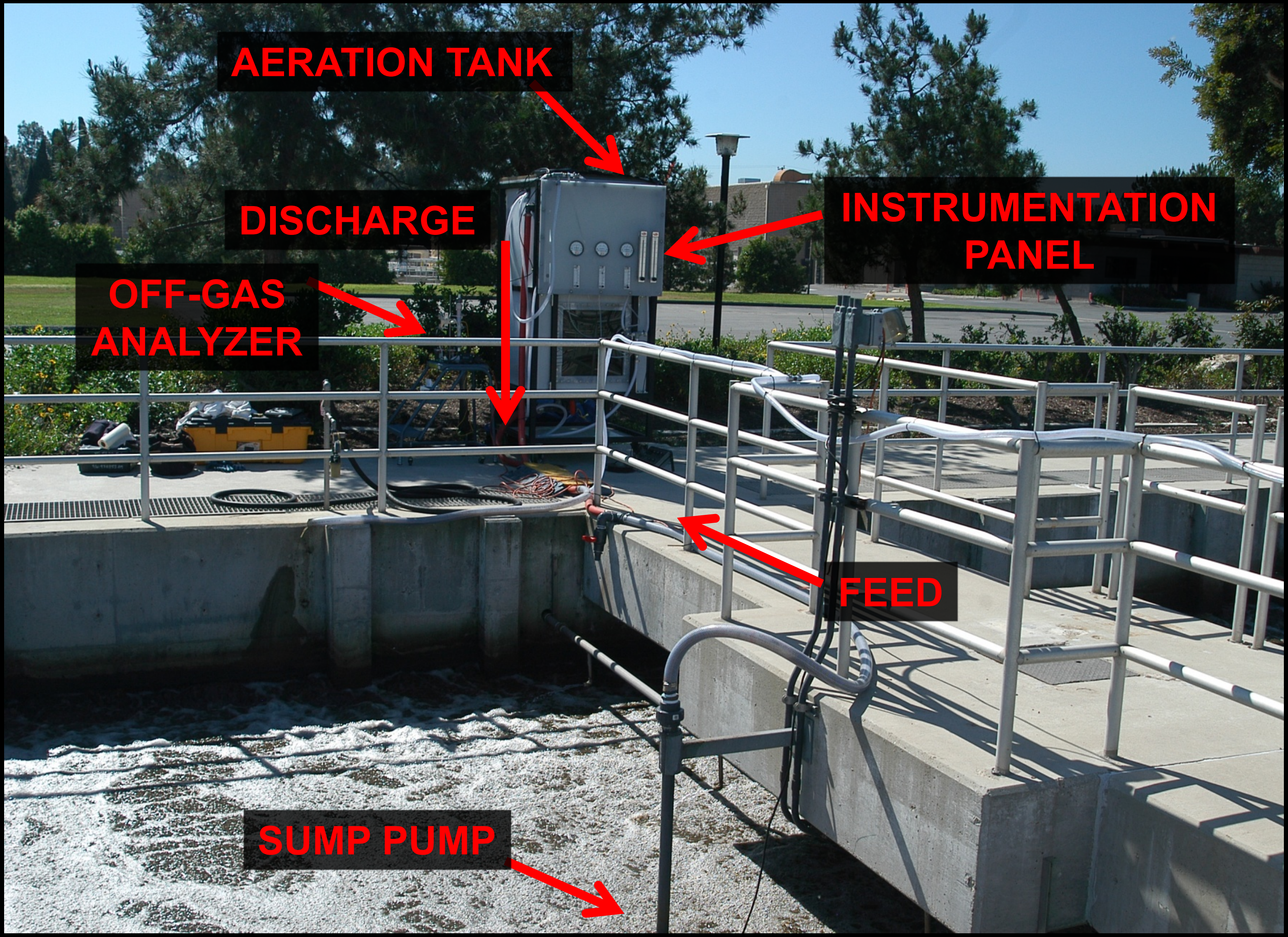
Bubble release at operating regime

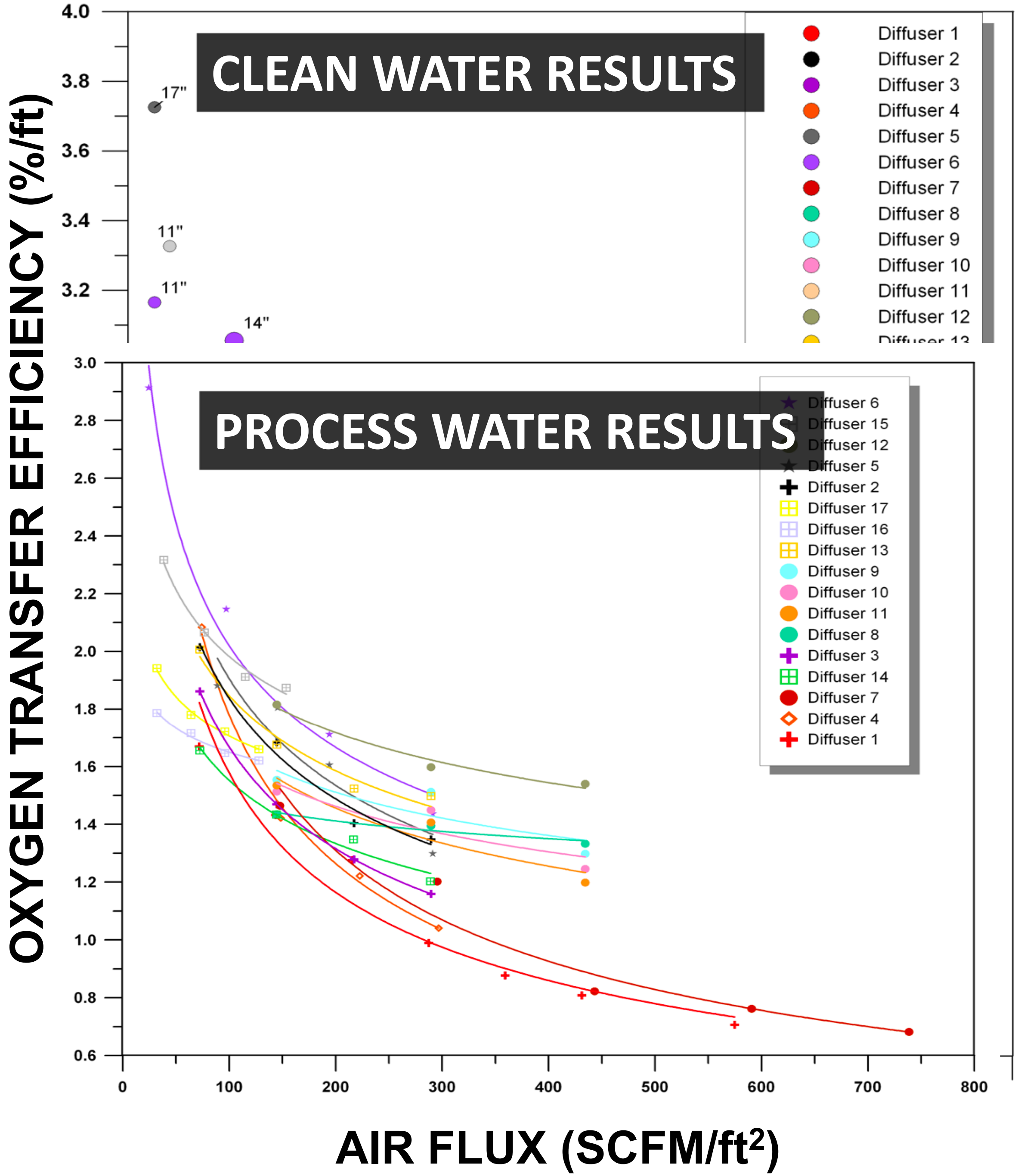


ON-SITE COLUMN TESTING IN WWTPs



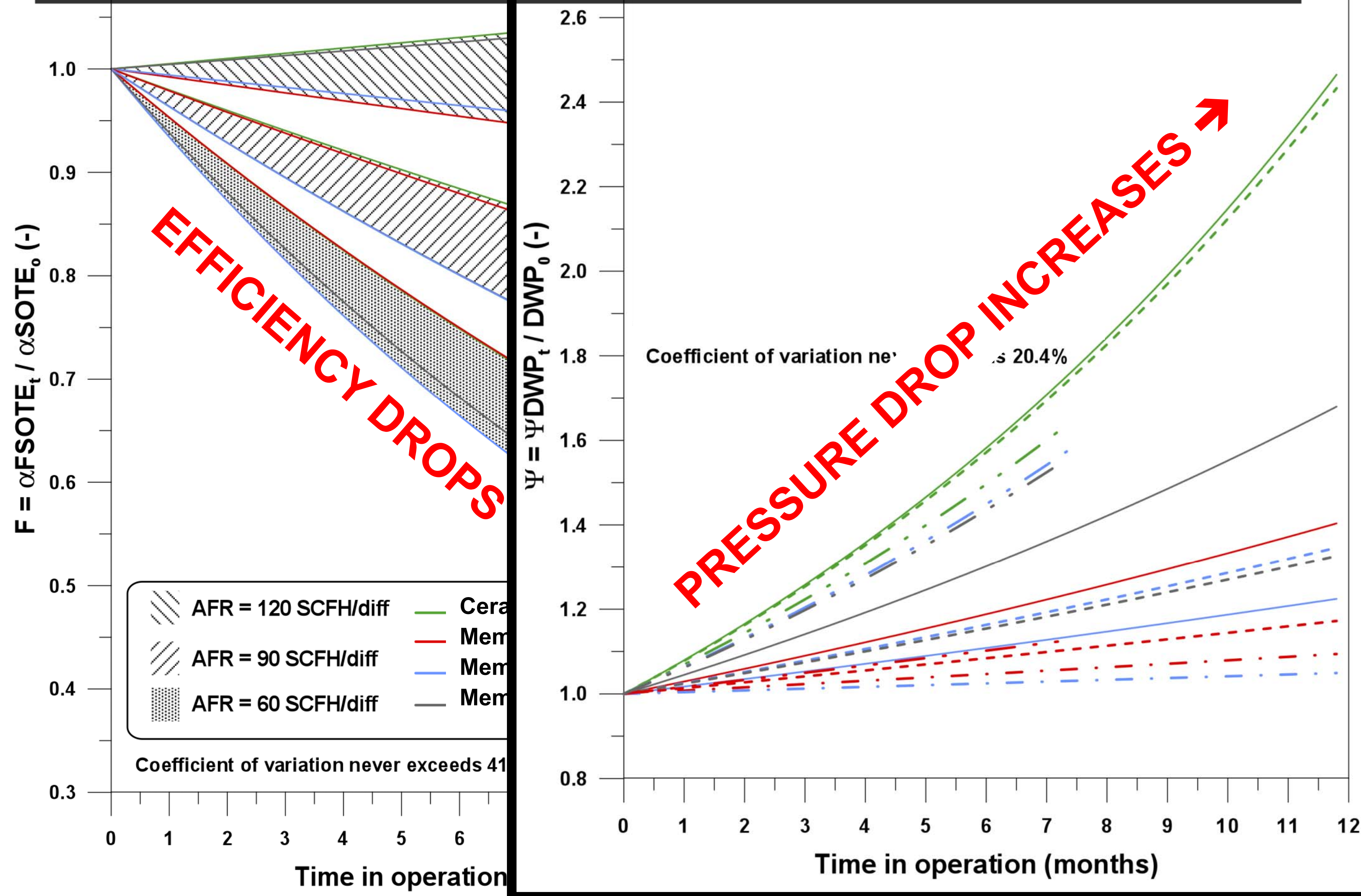
Bridging Present and Future : Fouling Studies





CLEAN WATER RESULTS
PROCESS WATER RESULTS
OXYGEN TRANSFER EFFICIENCY (%/ft)
AIR FLUX (SCFM/ft²)
17"
11"
11"
14"
Diffuser 1
Diffuser 2
Diffuser 3
Diffuser 4
Diffuser 5
Diffuser 6
Diffuser 7
Diffuser 8
Diffuser 9
Diffuser 10
Diffuser 11
Diffuser 12
Diffuser 6
Diffuser 15
Diffuser 12
Diffuser 5
Diffuser 2
Diffuser 17
Diffuser 16
Diffuser 13
Diffuser 9
Diffuser 10
Diffuser 11
Diffuser 8
Diffuser 3
Diffuser 14
Diffuser 7
Diffuser 4
Diffuser 1
4.0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0
100
200
300
400
500
600
700
800

FOULING & PRESSURE DROP RESULTS



Fine-pore diffusers: clean them or don't buy them

V. LABORATORY DIFFUSER TESTING

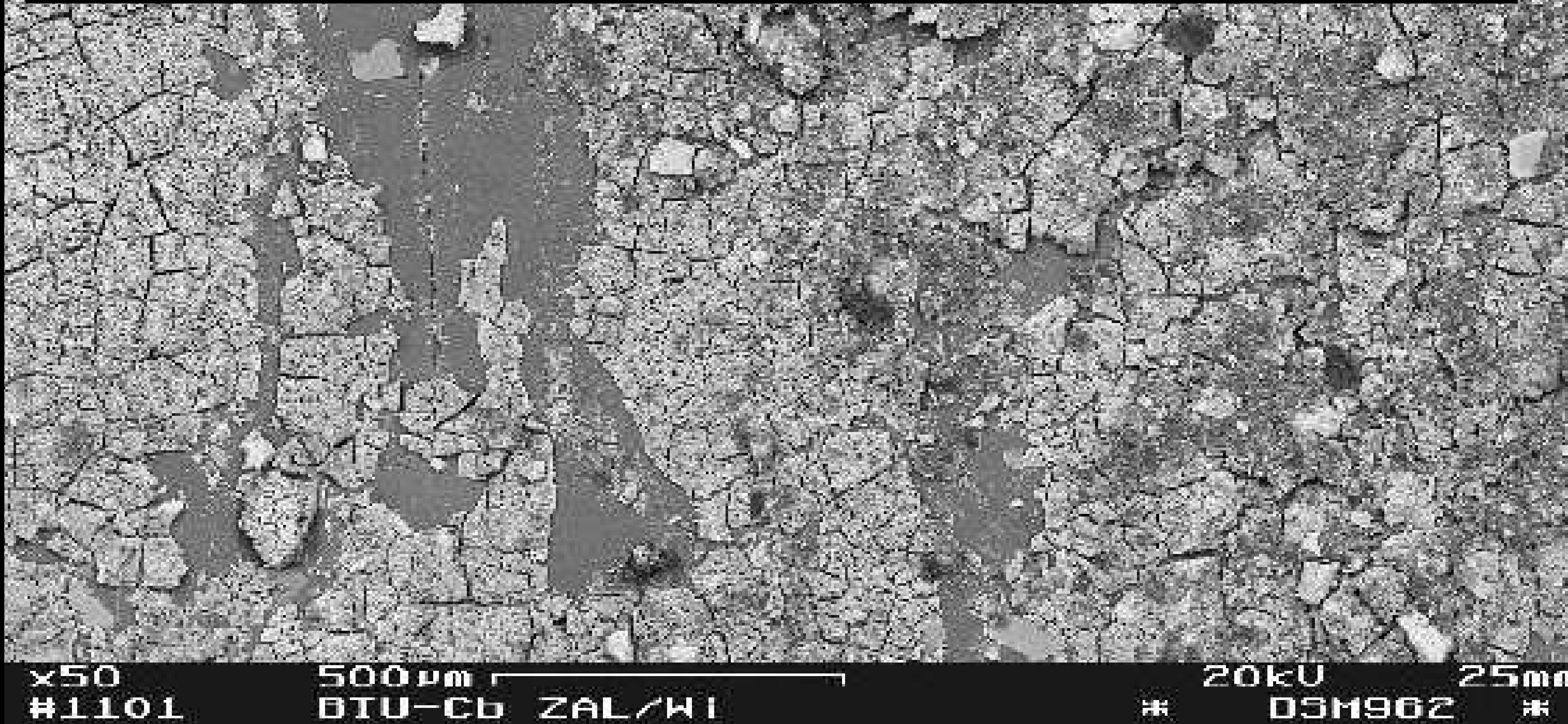
Optical Microscopy

- Suitable for imaging orifice dimensions and geometry
- Rapid and not labor-intensive
- HD cameras used
- Suitable to test diffusers while operating on bench-top mounts at variable air flows

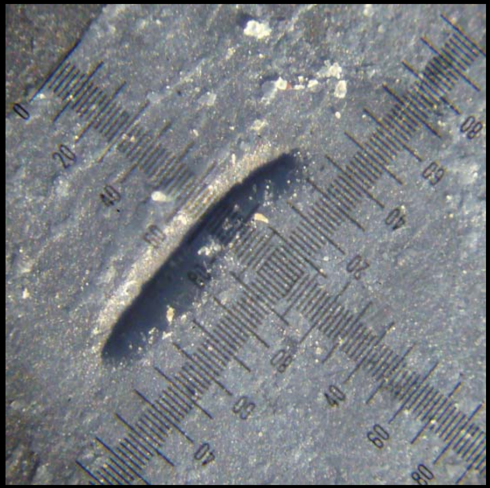
- Example of a silicone membrane pore ➔

Electron Microscopy

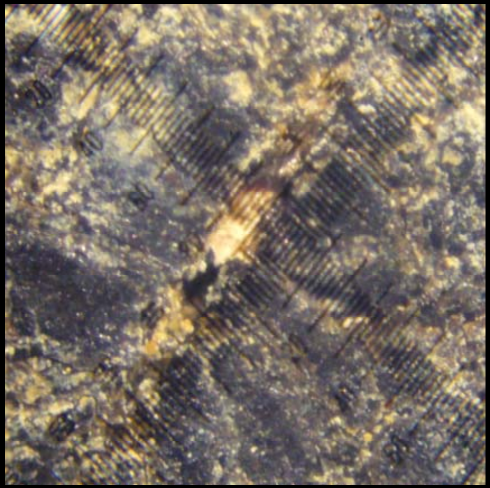
Example of using electronic microscopy to characterize surface deposits onto membrane diffusers. This was a silicone diffuser membrane in an industrial treatment plant, showing a combination of inorganic scales and biological fouling (Rosso et al, 2008).



Optical evidence of orifice clogging



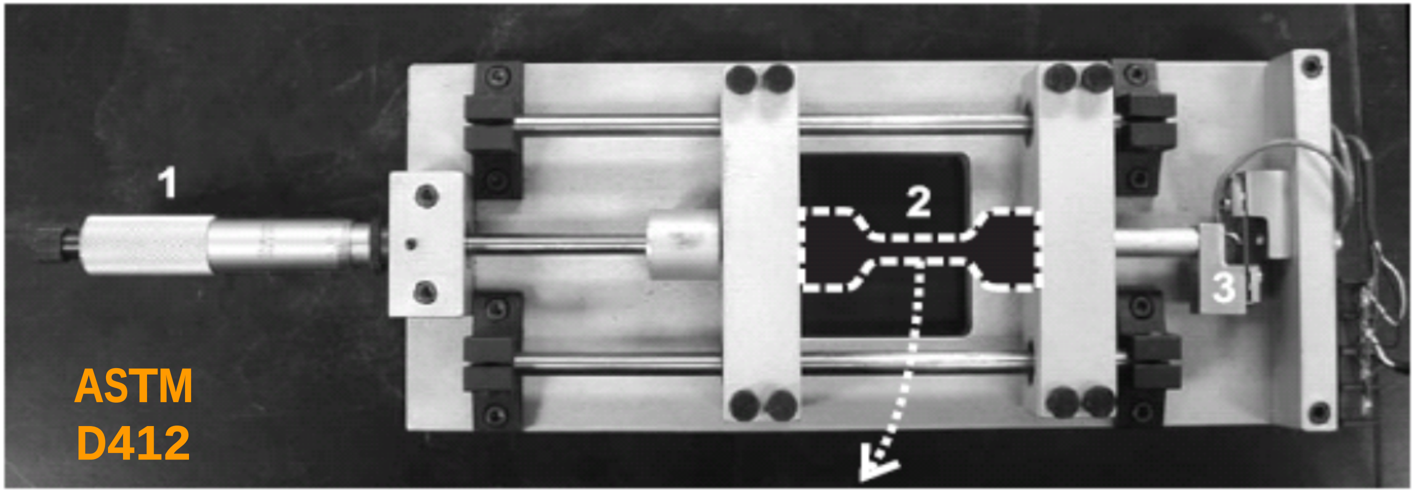
New

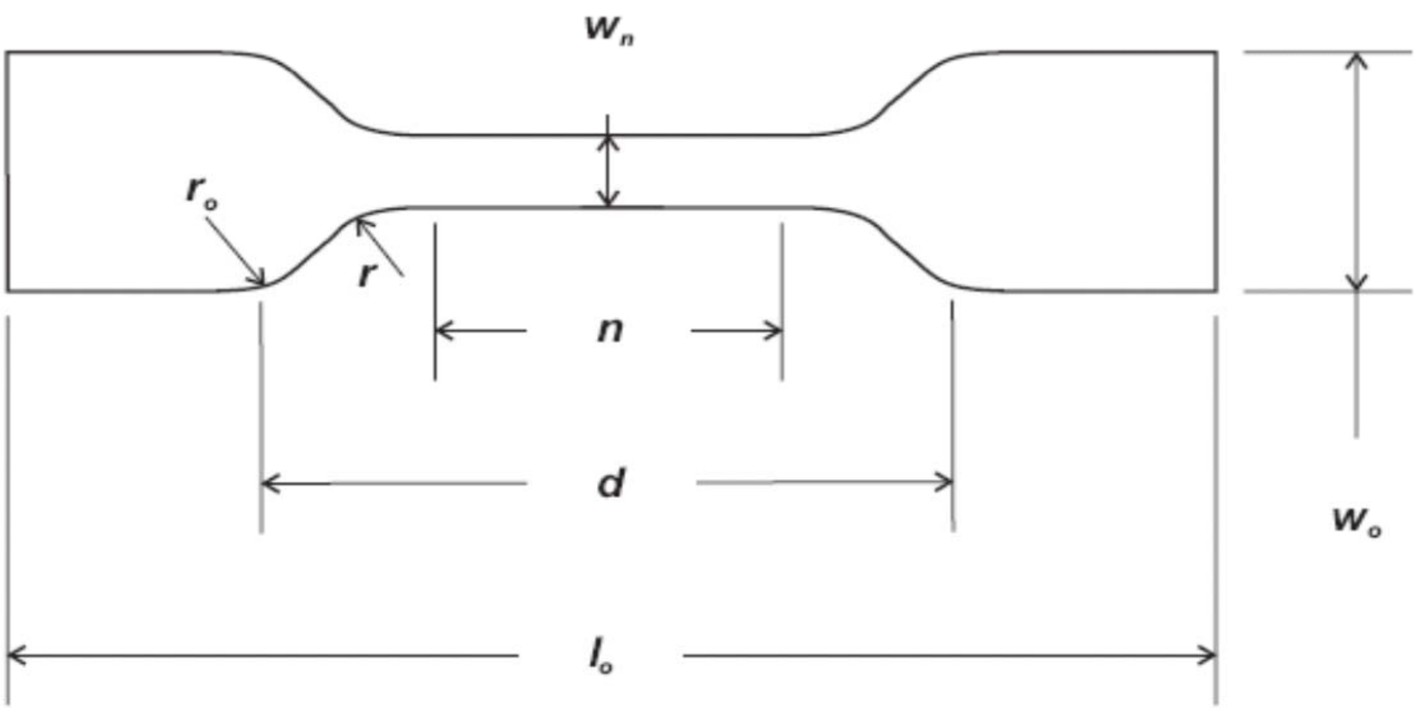


Fouled

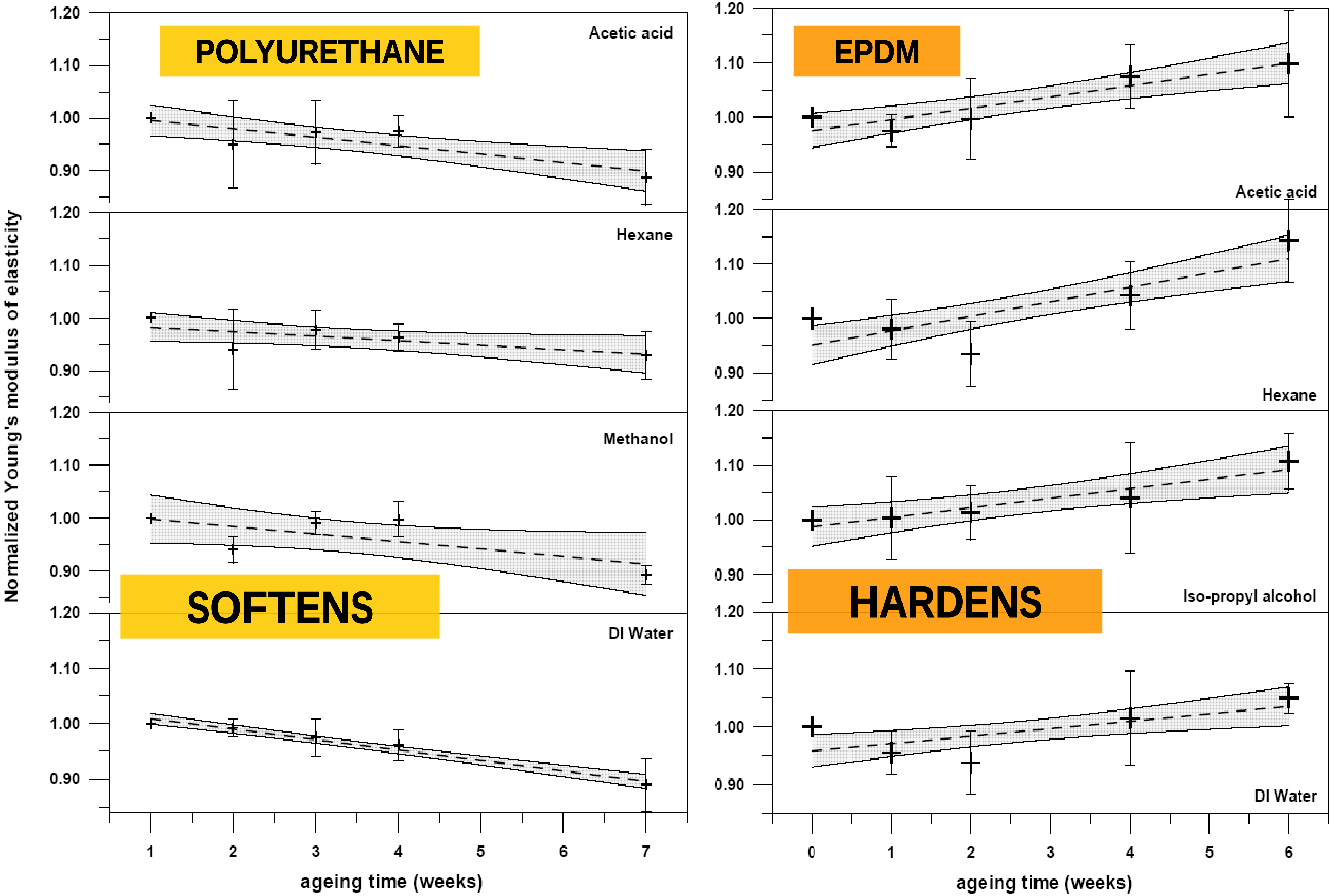
Cleaned

Loading Cell – Stress vs. Strain





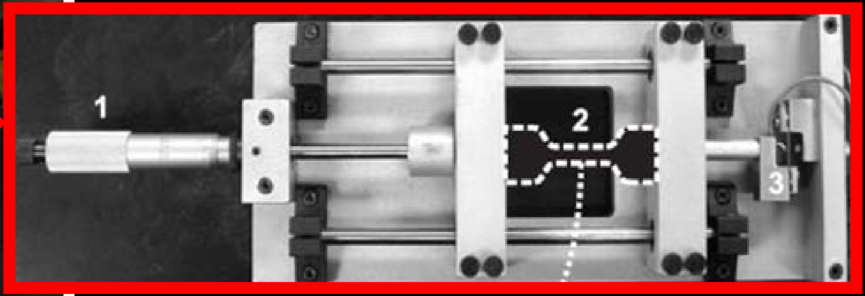
YOUNG'S MODULUS



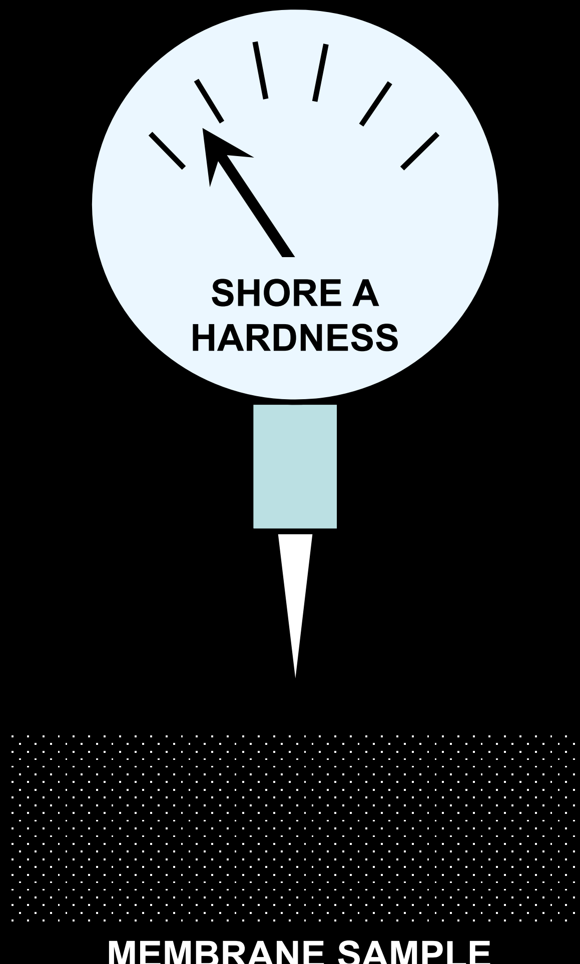
Thickness

- Micrometric measurements for thickness
- Pressure-sensitive micrometer used
- 10 membrane points sampled
- 4-8 fold membrane thicknesses

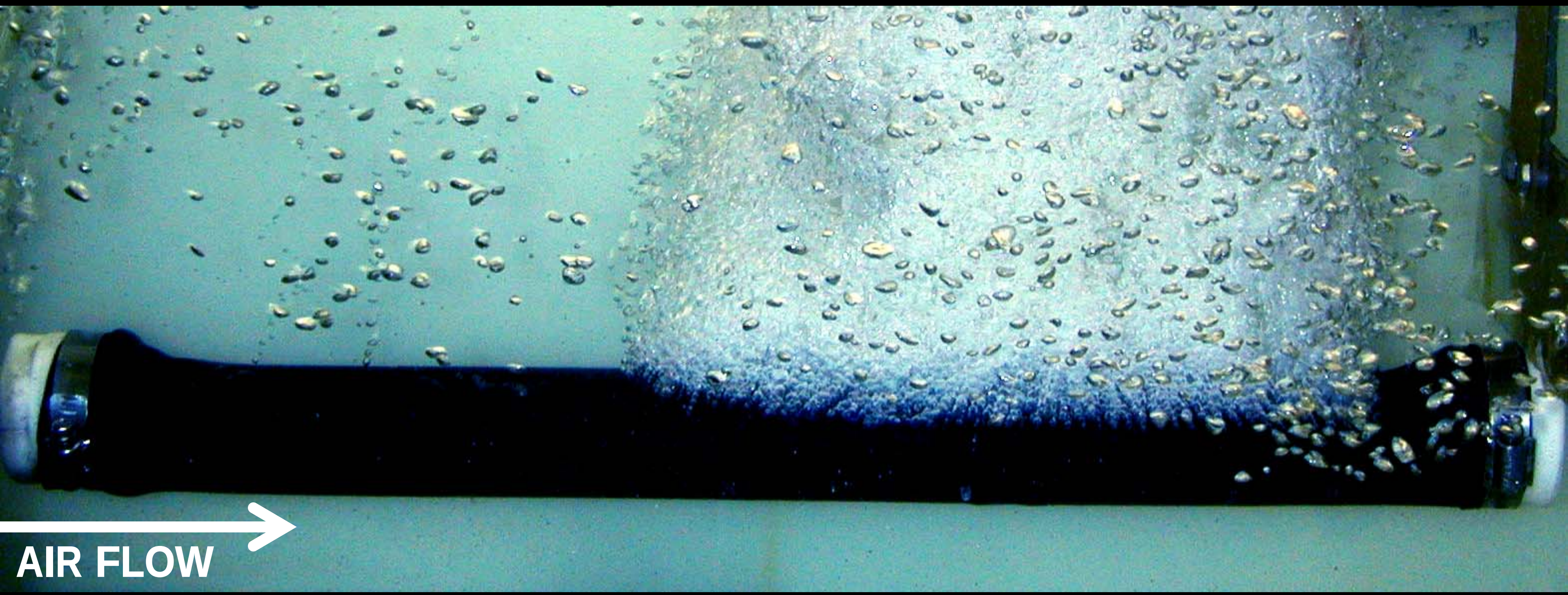
ORIFICE CREEP TESTS

DUROMETRIC TESTS

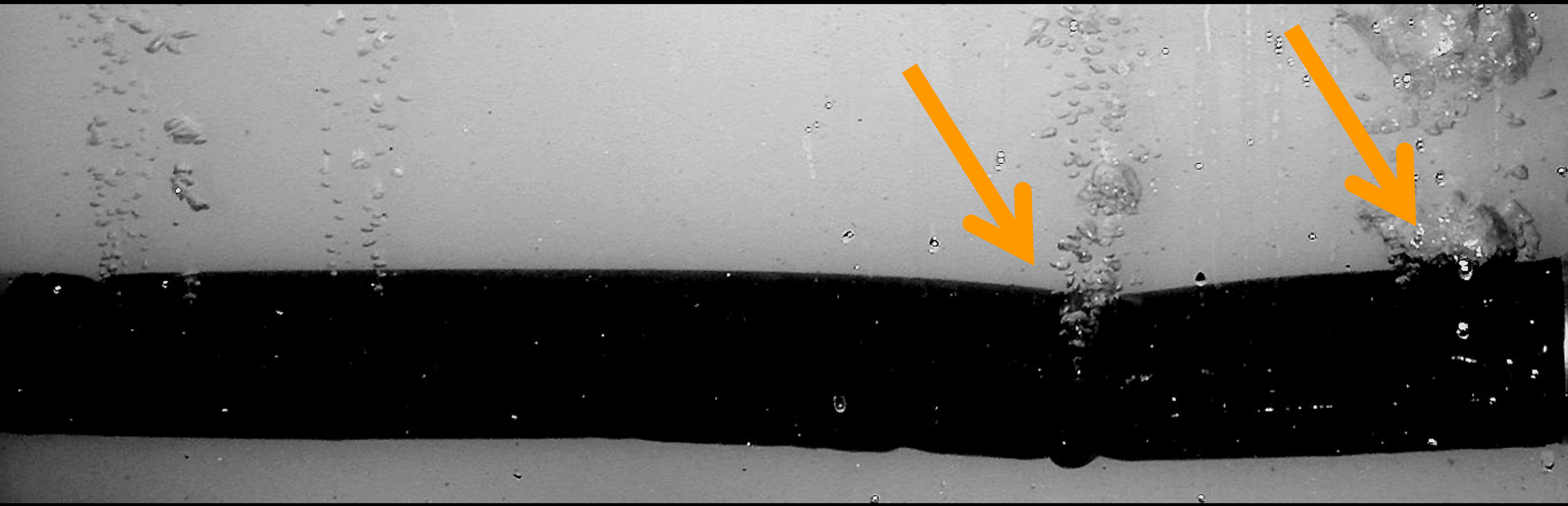


HALF & HALF



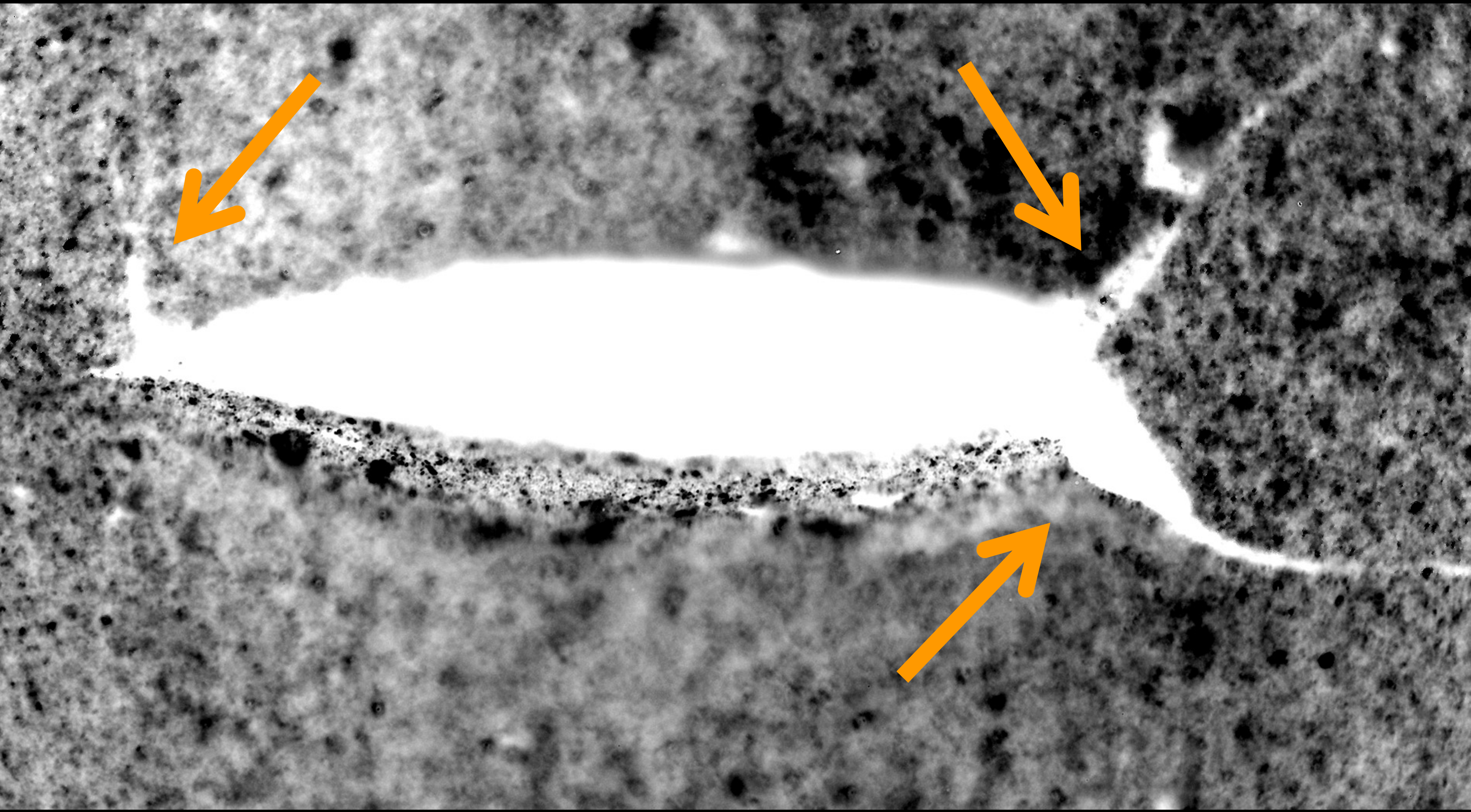
- Orifice creep caused sludge to enter the diffuser and form a crust inside

CRACKS IN FOLD

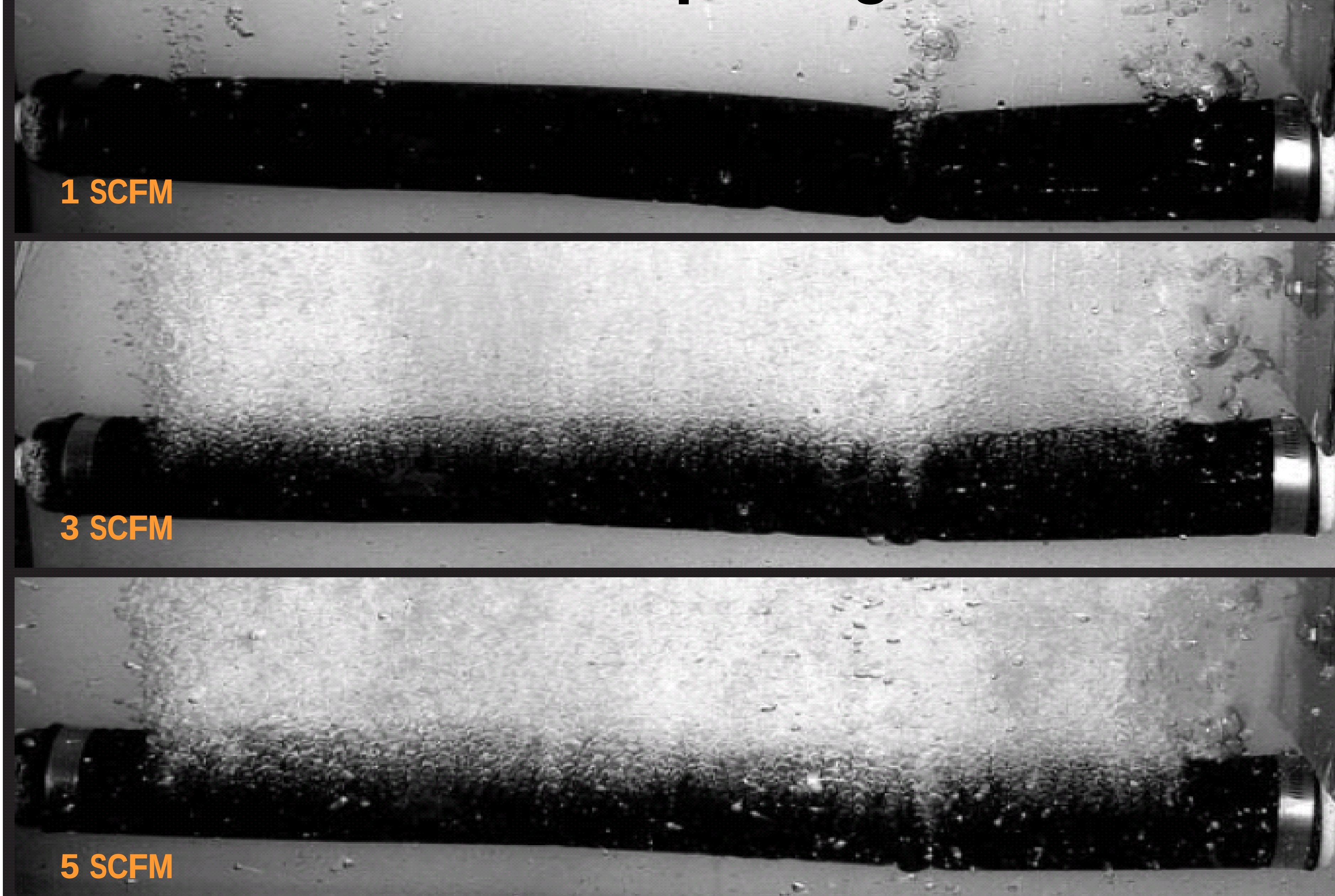


- Membrane sheath typically longer than frame
- To compensate for shrinkage
- Folds are formed

CRACKS IN FOLD



Minimum Pore Opening Threshold



VI. AERATION MODELING AND ENERGY FOOTPRINT ANALYSIS

IN MY BACKYARD

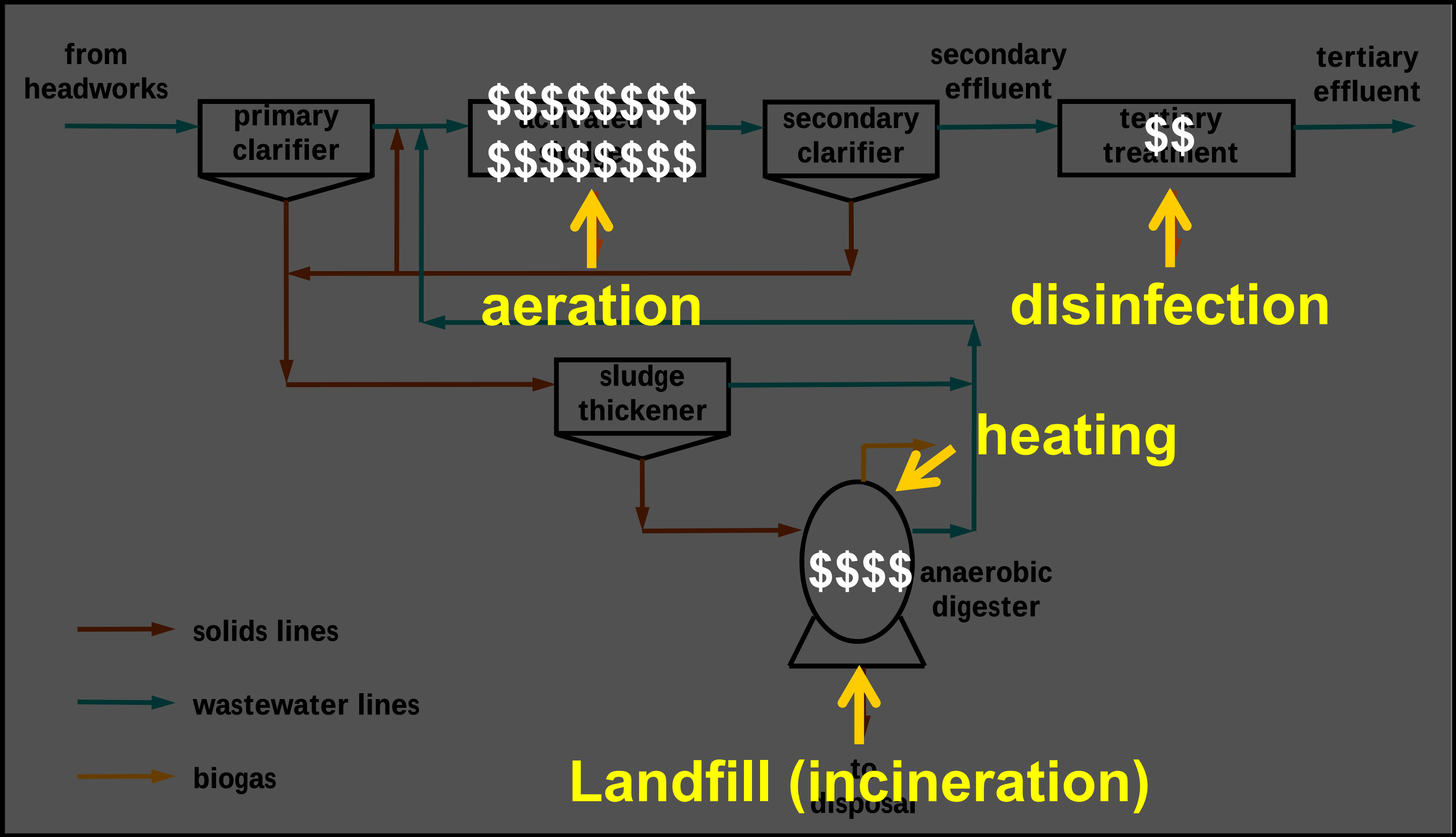
- In CA, water conveyance is the largest energy consuming industry (~15%: 30,000 GWh)

- Water/Wastewater Treatment is second! (~6%)

- Wastewater Aeration ~ 45-75% of treatment energy

Data: CEC (2005); Rosso and Stenstrom (2005)

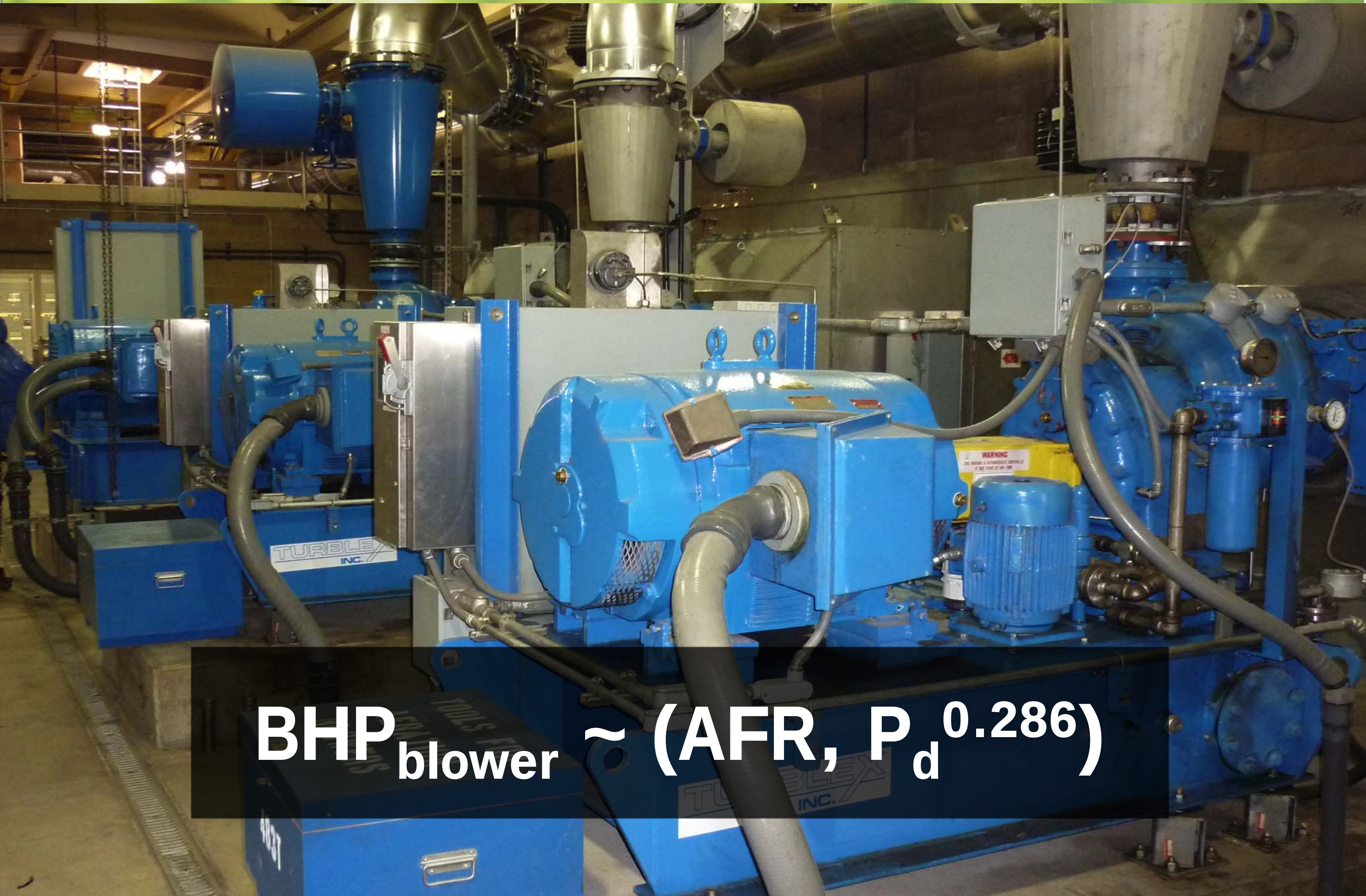
ENERGY FOOTPRINT



Aeration cost = 45-75% of plant energy (w/o influent/effluent pumping)

Rosso and Stenstrom (2005) *Wat. Res.* 39: 3773-3780

BLOWER POWER



$$BHP_{blower} \sim (AFR, P_d^{0.286})$$

AERATION & ENERGY FOOTPRINT

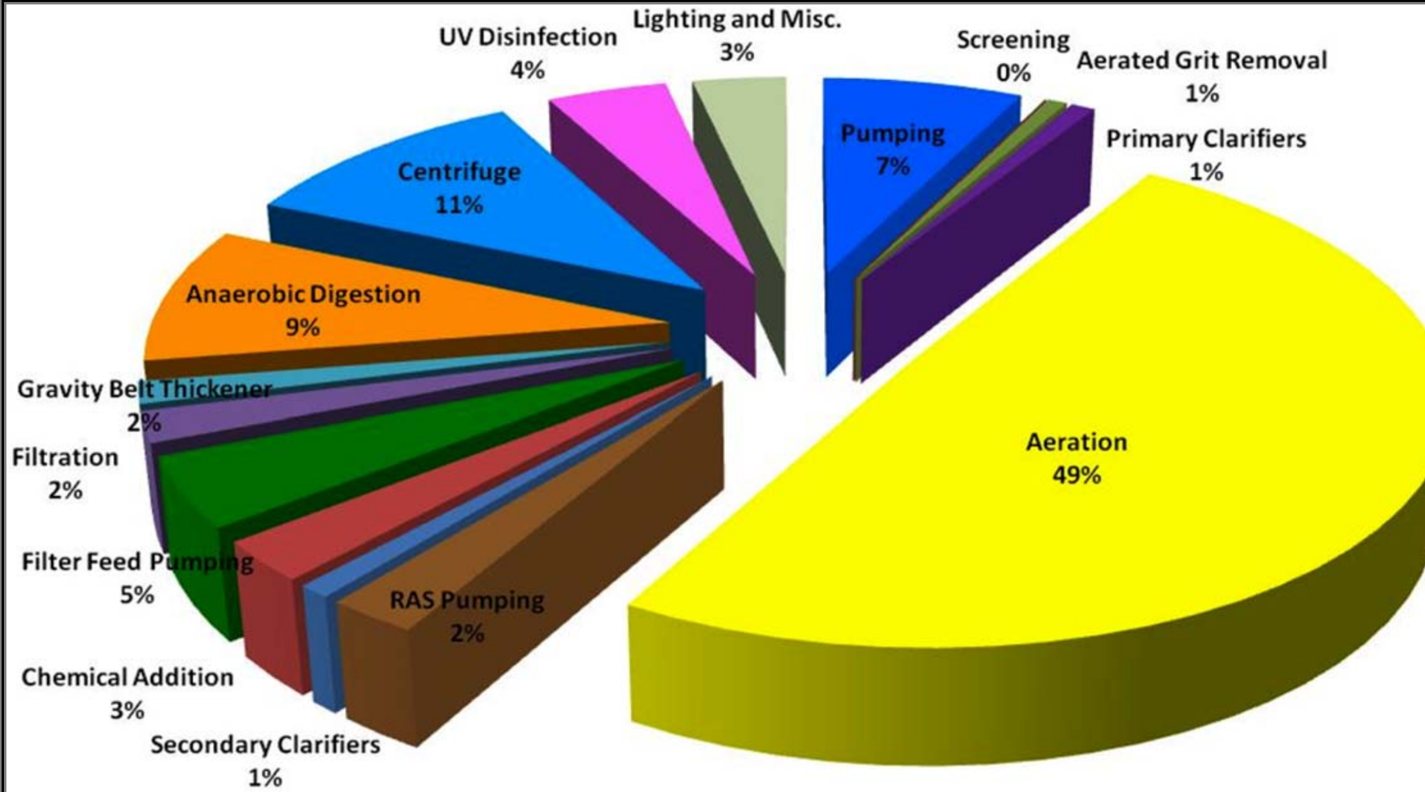
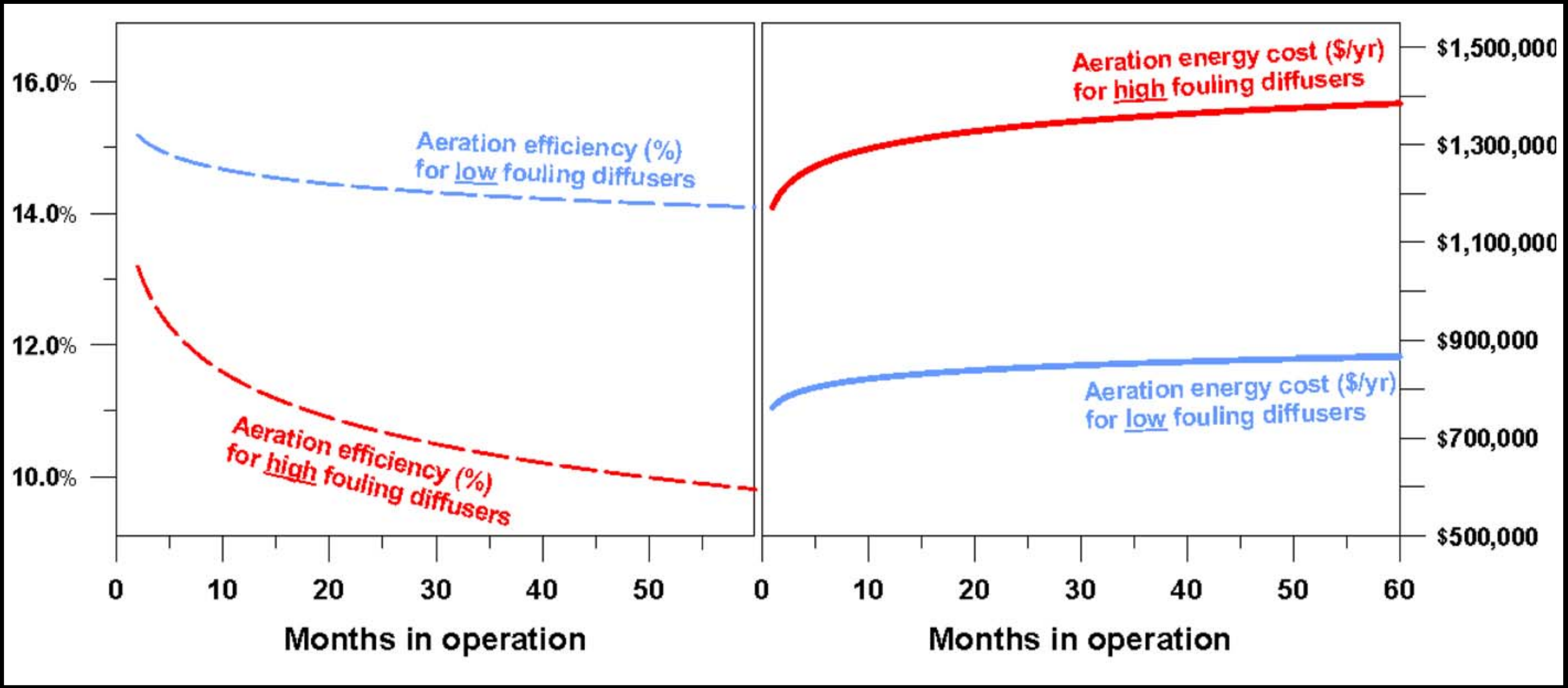


Figure 1. Estimated power usage for a typical 20MGD activated sludge facility performing wastewater treatment with nitrogen removal in the United States (MOP32, 2009).

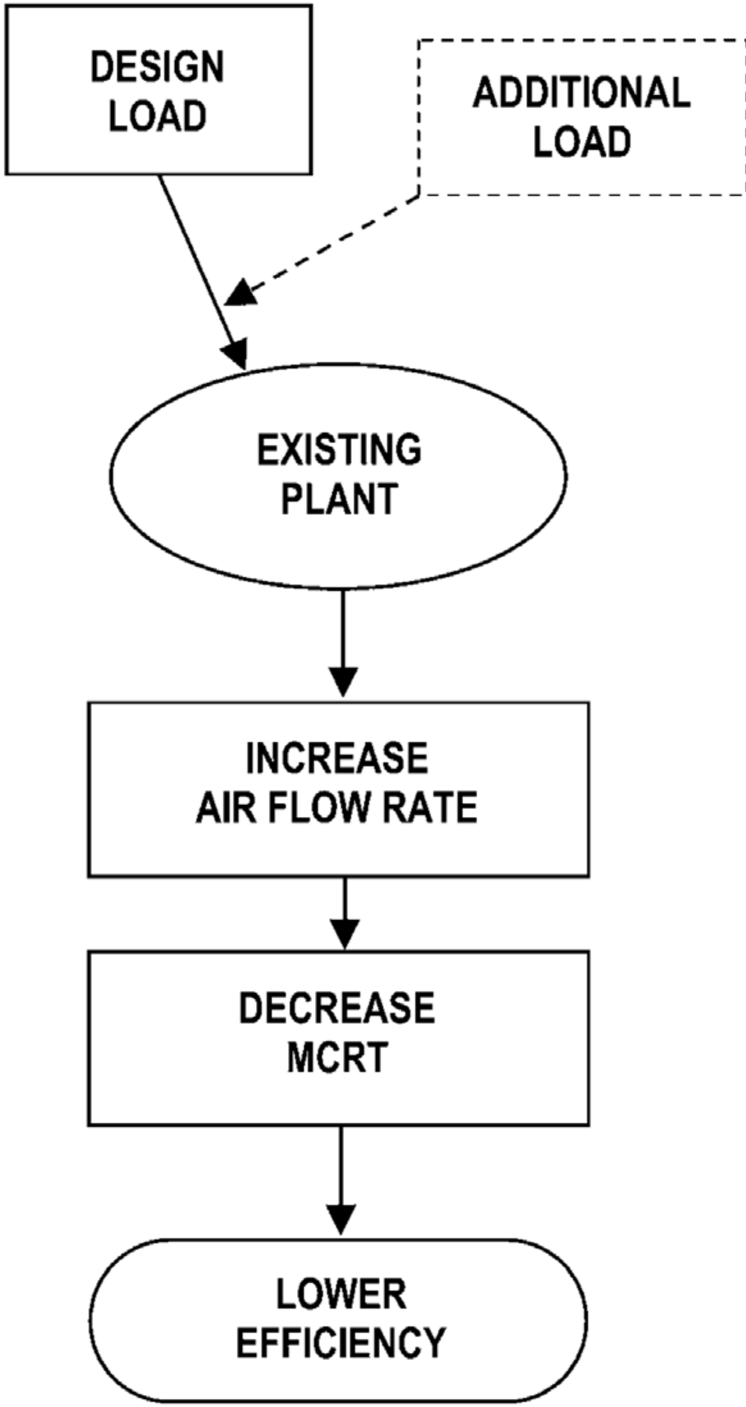
Aeration cost = 45-75% of plant energy (w/o influent/effluent pumping)

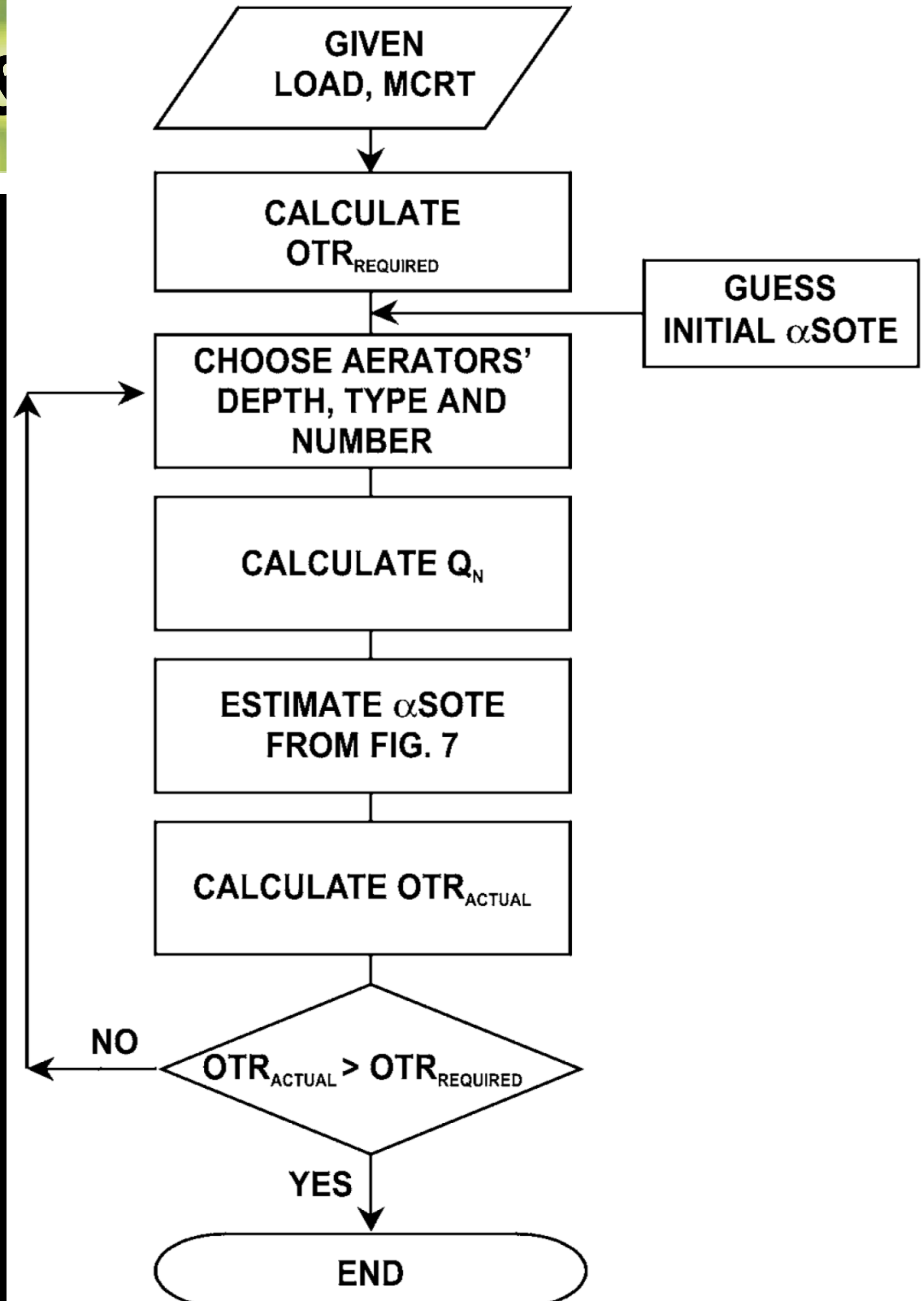
Rosso and Stenstrom (2005) *Wat. Res.* 39: 3773-3780

Process condition, ⟨SOTE, and $/yr



Aeration efficiency (%, oxygen transferred to the wastewater divided by the oxygen actually blown through the wastewater) and energy cost ($/yr) estimation for US installations employing low and high fouling diffusers. The aeration energy cost here is estimated conservatively as the pure energy cost of blowing air (i.e., the additional maintenance required to run an inefficient system is not included). The difference between the initial values in the two graphs is due to differences in diffuser pressure drop.

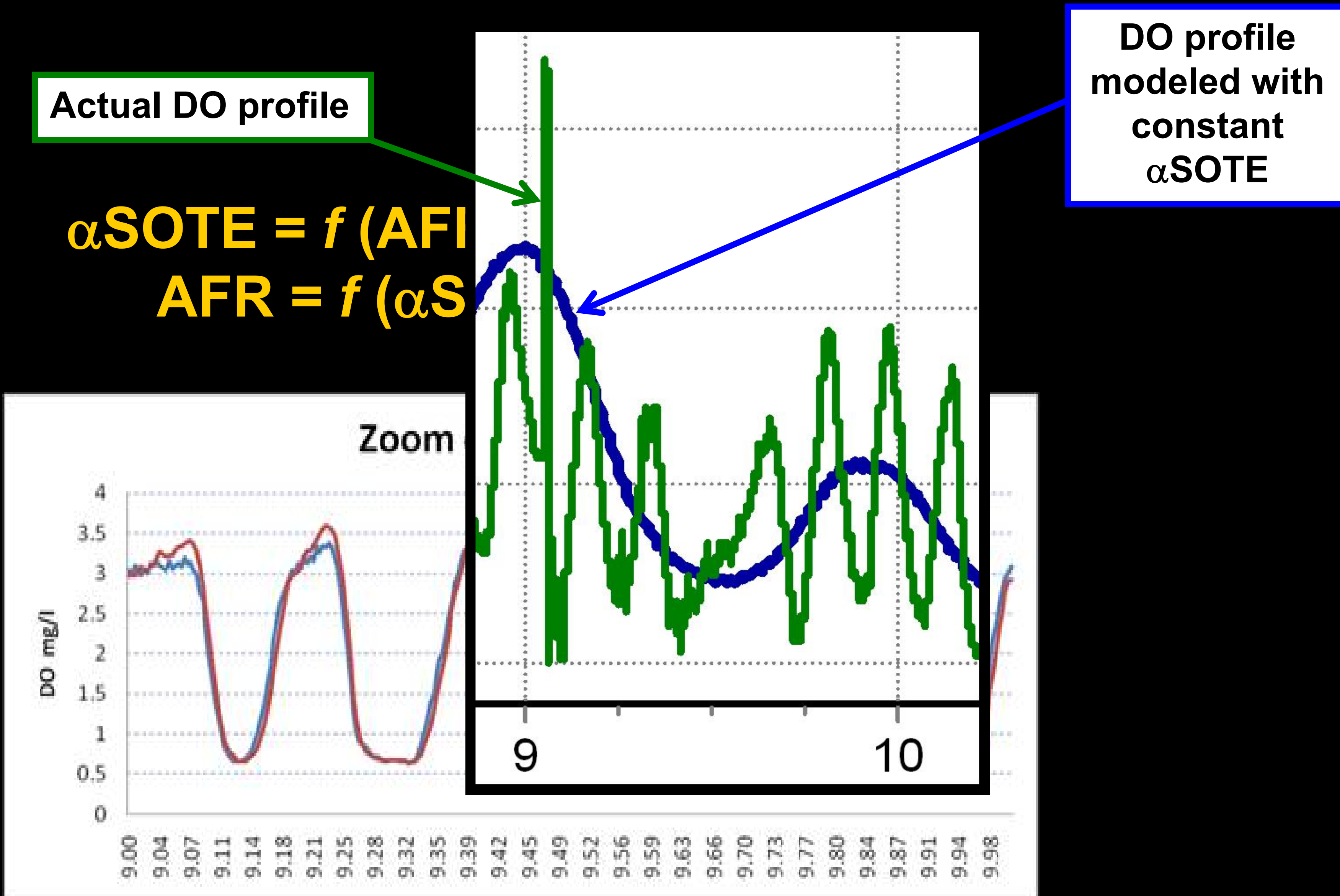

DESIGN LOAD
ADDITIONAL LOAD
EXISTING PLANT
INCREASE AIR FLOW RATE
DECREASE MCRT
LOWER EFFICIENCY


GIVEN LOAD, MCRT
CALCULATE $OTR_{REQUIRED}$
GUESS INITIAL αSOTE
CHOOSE AERATORS' DEPTH, TYPE AND NUMBER
CALCULATE Q_N
ESTIMATE αSOTE FROM FIG. 7
CALCULATE OTR_{ACTUAL}
$OTR_{ACTUAL} > OTR_{REQUIRED}$
NO
YES
END

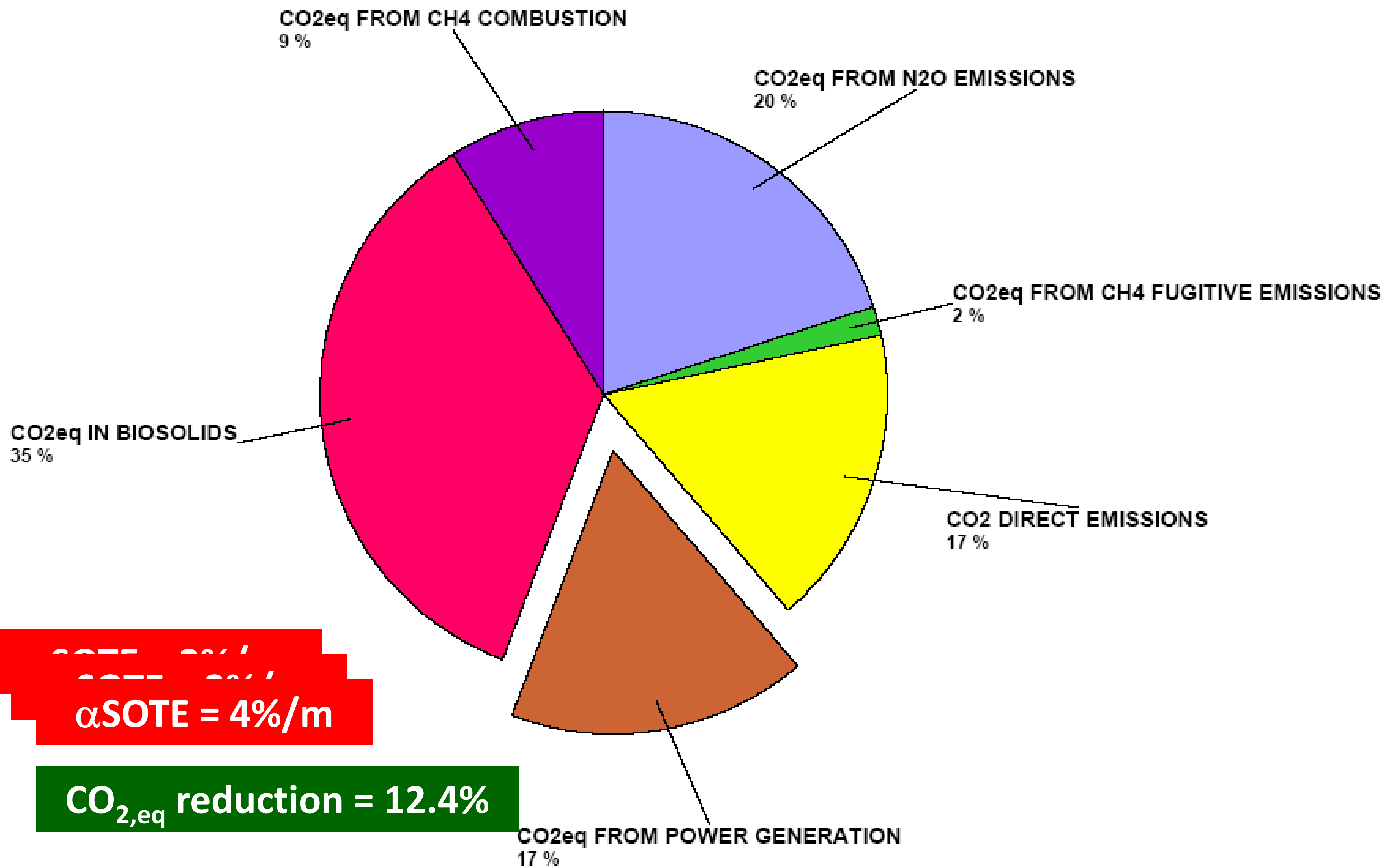
Static vs. dynamic aeration modeling

αSOTE = *f* (AFI

AFR = *f* (αS



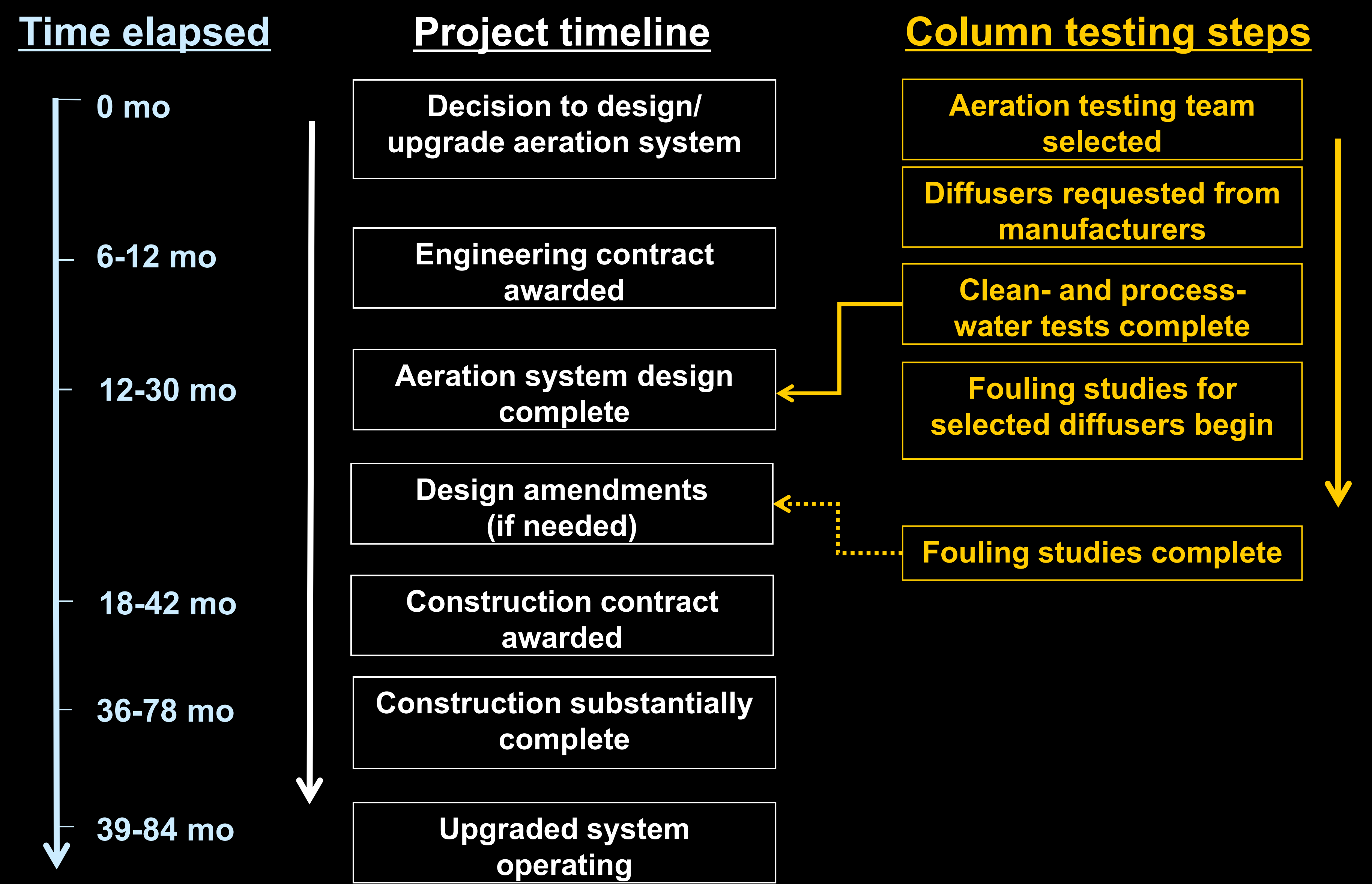
Weight of aeration efficiency on process CFP



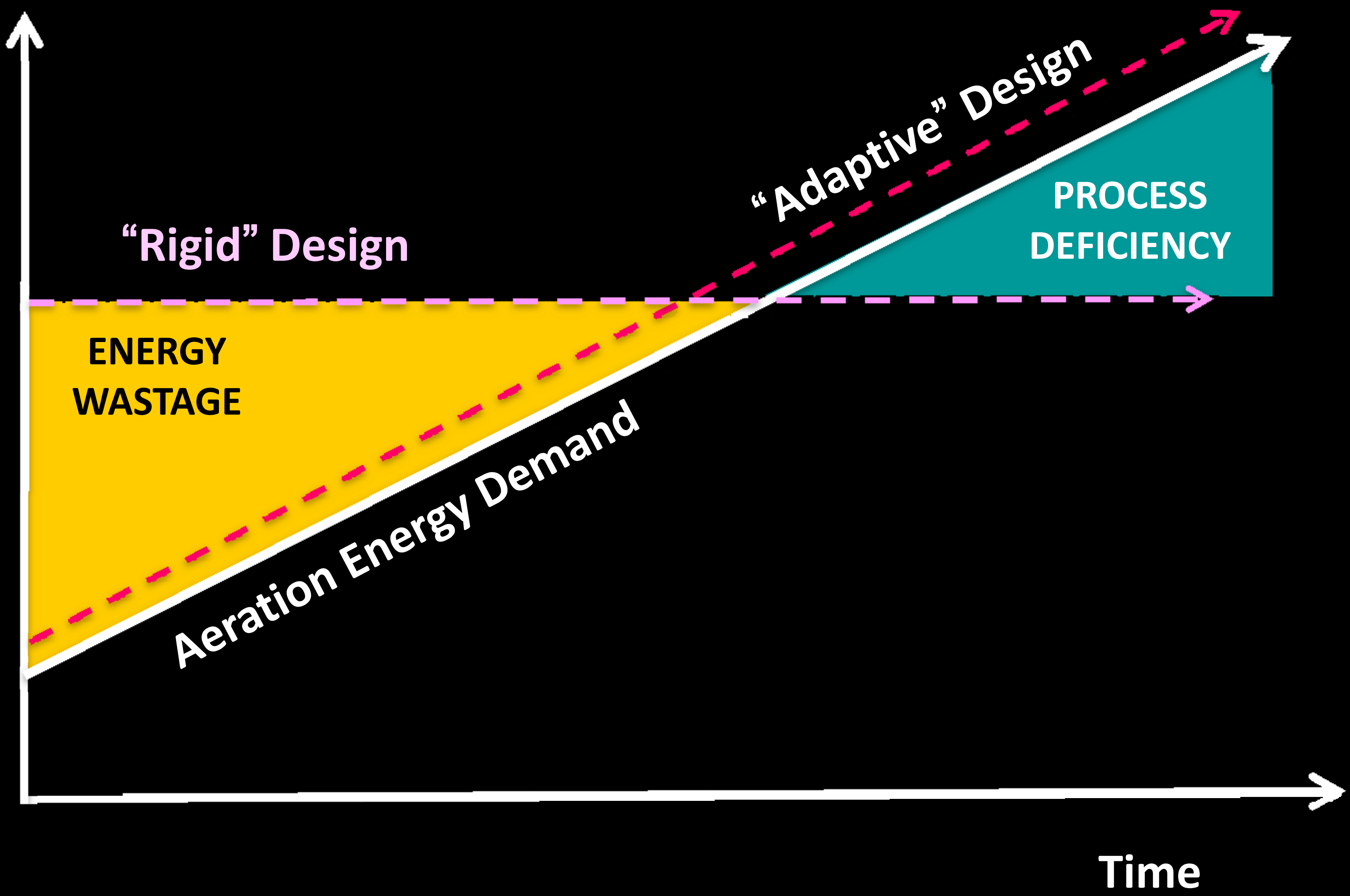
αSOTE = 4%/m

$CO_{2,eq}$ reduction = 12.4%

New design/upgrade paradigm



"Rigid" vs. "Flexible" Design



VII. CONCLUSIONS

CONCLUSIONS

- Contaminants accumulation depresses oxygen transfer and causes an increase in energy usage
- Aeration system and biological process layout influence oxygen transfer efficiency
- Real-time efficiency analyzers are available
- 24hr observations necessary for highest energy savings and for truly dynamic modeling
- Long-term studies quantify fouling effects and cleaning schedules
- Dynamic modeling allows the largest energy and carbon footprint minimization

?

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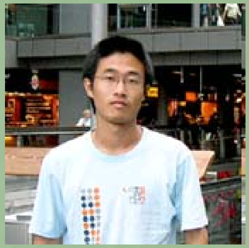
EPL

ENVIRONMENTAL PROCESS LAB



- **Rosso et al (2005)** *Water Environment Research* **77, 266-273**
- **Rosso and Stenstrom (2005)** *Water Research* **39, 3773-3780**
- **Rosso and Stenstrom (2005)** *Water Environ. Res.* **78, 810-815**
- **Rosso and Stenstrom (2006)** *Water Research* **40, 1397-1404**
- **Rosso et al (2006)** *Water Science & Technology* **54(10), 143-153**
- **Rosso and Stenstrom (2007)** *Environmental Engineer* **43(3), 29-38**
- **Stenstrom et al (2008)** *Water Environ. Res.* **80(7), 663-671**
- **Kaliman et al (2008)** *Water Research* **42, 467-475**
- **Rosso et al (2008)** *Water Science & Technology* **57(7), 973-978**
- **Rosso et al (2008)** *Water Research* **42, 2640-2648**
- *Biological Wastewater Treatment* **(2008), IWA Publishing**
- **Rosso and Stenstrom (2008),** *Chemosphere* **70, 1468-1475**
- **Lippi et al (2009)** *Water Science & Technology* **59(1), 125-131**
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