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BEFORE WE BEGIN

• SILENCE CELL PHONES & PAGERS

• QUESTION AND ANSWER SESSION WILL FOLLOW PRESENTATION

• SEMINAR SLIDES WILL BE POSTED ON MWRD WEBSITE AT (www. MWRD.org)

• Home Page ⇒ (Public Interest) ⇒ more public interest ⇒ M&R Seminar Series ⇒ 2012 Seminar Series

• SEMINAR VIDEO IS STREAMED ON-DEMAND AND CAN BE ACCESSED FROM www.MWRD.org website via RSS Feed
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Association of Environmental Engineering and Science Professors,

Engineers Without Borders.

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OXYGEN TRANSFER IN WASTEWATER TREATMENT PROCESSES:
RESEARCH PERSPECTIVES IN THE 21ST CENTURY

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MWRDGC Monthly Seminar
Stickney Water Reclamation Plant
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I. EFFECTS OF WASTEWATER CONTAMINANTS ON OXYGEN TRANSFER
**Terminology**

**OTE:** Oxygen Transfer Efficiency (%)  

**OTR:** Oxygen Transfer Rate (kg\(_{O_2}\)/h)  

**SOTE:** Standardized OTE in clean water (%)  

\( \alpha_{SOTE} \): Standardized OTE in process water (%)  

\( \alpha = \alpha_{SOTE}/SOTE \) (water quality estimate)  

\( F = \text{Fouling factor} = \frac{\alpha_{SOTE_{old}}}{\alpha_{SOTE_{new}}} \)  

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

\( \Psi = \text{Pressure factor} = \frac{DWP_{old}}{DWP_{new}} \)
$\alpha$: 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

\((O_2 \text{ transferred} / O_2 \text{ fed})\)

<table>
<thead>
<tr>
<th>Cost</th>
<th>efficiency</th>
<th>trtmt requirement</th>
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\[ \text{AFR} = f(\alpha, \text{SOTE}, R_0) \]

\[ $$$ \quad \text{ww} \quad \text{aerator} \quad \text{ww} \]
**WHAT ARE THESE CONTAMINANTS?**

<table>
<thead>
<tr>
<th>CONTAINS:</th>
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<tbody>
<tr>
<td>15-25% anionic surfactants</td>
</tr>
<tr>
<td>0-15% non-ionic surfactants</td>
</tr>
<tr>
<td>0-15% soap</td>
</tr>
<tr>
<td>0-15% cationic surfactants</td>
</tr>
<tr>
<td>fillers to 100%</td>
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</tbody>
</table>
LOW INTERFACIAL VELOCITY = HIGH SURFACTANT ACCUMULATION = HIGH GAS TRANSFER DEPRESSION

HIGH INTERFACIAL VELOCITY = LOW SURFACTANT ACCUMULATION = LOW GAS TRANSFER DEPRESSION
CONVENTIONAL LAYOUT

DO (mg/l)

~0  0.2  0.5  0.8  1.0

influent

RAS

rbCOD
Alpha: Conventional vs. NDN

AERATION ENERGY ~ $1/\alpha F$

NDN
MCRT ~ 13d

CONVENTIONAL PROCESS
MCRT ~ 3d

ANOXIC SELECTOR
($\alpha$ not defined)

Conventional
MCRT ~ 3d
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

- **DO (mg/l)**
- **OFF-GAS yO2 (%)**

- **Na₂SO₃ added**
- **O₂ scavenging completed**
- **Cₜₐₜ is reached**

*Figure shows a plot with time (min) on the x-axis and DO (mg/l) on the y-axis, with points indicating key events.*
III. FIELD MEASUREMENTS OF OXYGEN TRANSFER IN WASTEWATER
AERATION EFFICIENCY TESTING

$$\text{OTR} = (k_L a \cdot V) [C_{sat} - (\text{DO}_{exc} + \text{DO}_{needed})] = \text{kg} \text{O}_2/\text{d} = $$$/\text{d}$$

Off-gas
TRADITIONAL OFF-GAS TESTING SETUP

O₂, IN - O₂, OUT

OTE (%) = ________________

O₂, IN

Guy with a Ph.D.

OFF-GAS ANALYZER

HOOD
PITFALLS OF TESTING...
CURRENT OFF-GAS SETUP

AUTOMATED ANALYZER

MANUAL ANALYZER
Key: 1) off-gas hose (from collection hood); 2) reference air intake; 3) three-way valve; 4) time delay relay; 5) column for CO₂ and H₂O 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

Air flow rate (1000m$^3$/hour)

OTE from off-gas test (%)

Low plant flow period

10 PM 10 PM 10 AM 10 AM 10 PM

OTE from off-gas test

Air flow rate
24 hrs - PLANT OPERATIONS

Oxygen flows (kg h⁻¹)

O₂ demand

O₂ transfer

O₂ wastage

14:00 18:00 22:00 2:00 6:00 10:00
IV. LONG-TERM DIFFUSER FOULING
Aeration Efficiency over time

STANDARD AERATION EFFICIENCY

Fouling

Cleaning

After Stenstrom and Rosso (2008)

New
Used
Cleaned

Fine-pore
Turbines
Coarse-bubble
Surface aerator

After Stenstrom and Rosso (2008)
Big challenges
Discharge pressure is often limiting!
BLOWERS DO NOT COMPRESS AIR, THEY BLOW IT.
Plant histories of efficiency: $\langle SOTE \rangle$
Pre-cleaning
Post-cleaning
Bubble release at operating regime

More Open Pores
ON-SITE COLUMN TESTING IN WWTPs

Diagram showing setup for on-site column testing in wastewater treatment plants (WWTPs). The diagram includes components such as:

- Reference (Air) system
- Off-gas flow meter
- Vacuum system
- Submersible pump
- Mixed liquor outlet

The diagram illustrates the flow of gases and fluids through the testing setup, highlighting the integration of various components for efficient on-site testing.
CLEAN WATER RESULTS

PROCESS WATER RESULTS

OXYGEN TRANSFER EFFICIENCY (%/ft)

AIR FLUX (SCFM/ft²)
FOULING & PRESSURE DROP RESULTS

EFFICIENCY DROPS

PRESURE DROP INCREASES

Coefficient of variation never exceeds 4%

Coefficient of variation never exceeds 20.4%
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
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

ASTM D412
YOUNG’S MODULUS

POLYURETHANE

EPDM

SOFTENS

HARDENS
**Thick ness**

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

SHORE A HARDNESS

MEMBRANE SAMPLE
• Orifice creep caused sludge to enter the diffuser and form a crust inside
Membrane sheath typically longer than frame
To compensate for shrinkage
Folds are formed
CRACKS IN FOLD
Minimum Pore Opening Threshold

1 SCFM

3 SCFM

5 SCFM
VI. AERATION MODELING AND ENERGY FOOTPRINT ANALYSIS
- 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)

BHP blower ~ (AFR, P d 0.286)
AERATION & ENERGY FOOTPRINT

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

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 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.
\[ \alpha_{SOTE} = f(AFI) \]

\[ AFR = f(\alpha_{SOTE}) \]

**Static vs. dynamic aeration modeling**

Actual DO profile

DO profile modeled with constant \( \alpha_{SOTE} \)
Weight of aeration efficiency on process CFP

\[ \alpha_{\text{SOTE}} = 4\%/m \]

\[ \text{CO}_2,\text{eq reduction} = 12.4\% \]
**New design/upgrade paradigm**

**Project timeline**

- **0 mo**: Decision to design/upgrade aeration system
- **6-12 mo**: Engineering contract awarded
- **12-30 mo**: Aeration system design complete
- **18-42 mo**: Design amendments (if needed)
- **36-78 mo**: Construction contract awarded
- **39-84 mo**: Construction substantially complete

**Column testing steps**

- Aeration testing team selected
- Diffusers requested from manufacturers
- Clean- and process-water tests complete
- Fouling studies for selected diffusers begin
- Fouling studies complete
- Upgraded system operating
“Rigid” vs. “Flexible” Design

“Rigid” Design

ENERGY WASTAGE

Aeration Energy Demand

“Adaptive” Design

PROCESS DEFICIENCY

Time
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.
• Rosso and Stenstrom (2005) *Water Research* 39, 3773-3780
• *Biological Wastewater Treatment* (2008), IWA Publishing
• Rosso and Stenstrom (2008), *Chemosphere* 70, 1468-1475
• Leu et al (2009) *Water Practice & Technology* 3(3)
• Kim et al (2009) *IEEE*