Combining Energy Savings Efforts w/Nutrient Removal In Mind

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Activated Sludge Savings Opportunities

- Aeration – 40% to 60% of plant energy costs
  - Blowers
  - Diffusers
  - Air Flow and D.O. Control
  - Process Options
Blower Types & Drives

- Centrifugal  Single-stage or Multi-stage
  - Variable Speed
  - Constant speed with inlet throttling
- Positive Displacement
  - Variable Speed
- Hi Speed Turbo
  - Variable Speed
Single Stage Centrifugal Blower w/ Inlet Guide Vanes

- ~7,000 rpm MMSD blower
Single Stage Efficiency

- 30%-50% of maximum capacity
Positive Displacement Blower
– Vary Speed
Turbo Blower since 2005,
Developed by NASA

- ~60,000 rpm
Hi Speed Turbo Blower
Air Foil Bearing
## Typical Blower Efficiencies

<table>
<thead>
<tr>
<th>Blower Type</th>
<th>Nominal Blower Efficiency (percent)</th>
<th>Nominal Turndown (percent of rated flow)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive Displacement</td>
<td>45-65</td>
<td>50</td>
</tr>
<tr>
<td>Multi-Stage Centrifugal (inlet throttled)</td>
<td>50-70</td>
<td>60</td>
</tr>
<tr>
<td>Multi-Stage Centrifugal (variable speed)</td>
<td>60-70</td>
<td>50</td>
</tr>
<tr>
<td>Single-Stage Centrifugal, Integrally Geared (with inlet guide vanes and variable diffuser vanes)</td>
<td>70-80</td>
<td>45</td>
</tr>
<tr>
<td>Single-Stage High Speed Turbo **</td>
<td>70-82</td>
<td>50</td>
</tr>
</tbody>
</table>
Relative Blower Efficiencies
(+or- for ~16’ deep tank)

- PD Blowers 20-28 cfm/kw
- Multi-Stage Centrifugal 22-30 cfm/kw
- Single Stage Centrifugal 30-35 cfm/kw
- Hi Speed Turbo blowers 30-36 cfm/kw
Aeration Diffusers
Diffuser Efficiency
Terminology

- **OTE** -- Oxygen Transfer Efficiency
- **Alpha** -- Ratio of Dirty water to clean water transfer efficiency
- **SOTE** -- Standardized Transfer Efficiency – Corrected to zero D.O. & Standard Conditions
- **Alpha SOTE** – Standardized Transfer Efficiency in dirty water
- **Saturation Concentration** ~10.6 mg/l for 16’ deep tank
  - OTE is proportional to \((10.6 - \text{D.O.})/10.6\)
- **FOTE** -- Field Oxygen Transfer efficiency at actual D.O. in dirty water – the bottom line
Diffuser Efficiency Factors

- Diffuser – 1) fine bubble vs. coarse,
  2) ceramic vs. membrane,
  3) disc vs. sock or tube,

- Flux Rates for fine bubble diffusers

- Dissolved Oxygen Levels

- Process (Alpha) – 1) Long SRT vs. short SRT,
  2) Plug flow vs step feed
  3) Strength of Waste
Diffuser Efficiency and Flux Rate
– From EPA Manual


- Higher Efficiency
- Lower Air Flow per diffuser
- Denser Placement

Before 1981, the methods used to evaluate aerator performance under process conditions were inconsistent and coherent data on process water performance were extremely limited. Alpha is probably the most controversial and researched parameter used in translating clean water oxygen transfer data to actual field performance. Variables affecting the value of alpha include aerator type, nature of wastewater contaminants, position within the treatment scheme, process loading rate, bulk liquid DO, water depth, and air flow rate. Coherent data on alpha values for various aeration devices are limited. Alpha values of 0.25 to 1.53 have been published. Because much of the reported alpha data was obtained from bench-scale units (which did not properly simulate mixing and KLa levels, aerator type, water depth, and/or the geometry effects of their full-scale counterparts), these data are of questionable usefulness.
How Do You Test Efficiency?

Off-Gas Testing

- Measures FOTE
- With D.O.’s can calculate alpha SOTE
2002 Test - Effect of alpha and D.O. levels on efficiency

- Will anaerobic/anoxic zones affect alpha?
- Will low D.O. operation increase denitrification?
- Will low D.O. operation impact P removal?
Ceramic Diffusers in Madison
Ceramic Data – Alpha SOTE’s Full Scale Low D.O. Testing

**FIGURE 6**
Alpha SOTE’s During 2002 Off-Gas Testing

- **SOTE Pit3 7/10** (Normal Ops, Lo DO’s)
- **SOTE Pit4 7/15** (Normal Ops, Hi DO’s)
- **SOTE Pit4 9/28** (Test, Lo DO’s)
- **SOTE Pit4 11/6** (Test, Step Feed, Lo DO’s)
Dissolved Oxygen Data

FIGURE 4
D.O.'s During 2002 Off-Gas Testing
Field Transfer Efficiency

FIGURE 7
Field Oxygen Transfer Efficiencies
During 2002 Off-Gas Testing
and Weighted by Air Flow

- FOTE PI 3 7/10, 14.74% Wtd (Normal Ops, Lo DO's)
- FOTE PI 4 7/15, 10.87% Wtd (Normal Ops, Hi DO's)
- FOTE PI 4 8/28, 16.64% Wtd (Test, Lo DO's)
- FOTE PI 4 11/6, 14.50% Wtd (Test, Step. Feed, Lo DO's)
Results from Testing

- Operating with hi D.O.’s, resulted in 10.87% FOTE vs. 16.64%, 35% wasted air
- Operating in step feed resulted in 14.50% FOTE vs. 16.64%, 15% wasted air
- Related UW pilot and full scale work showed alpha variation in plug flow aeration section the same with and without selectors
- Low D.O. operation resulted in additional simultaneous nitrification/denitrification with no impact on P uptake and removal
Madison Membrane Tube Test
Layout
Off Gas Testing – Test Results

- The transfer efficiency should have improved because of lower flux rate—3X as much diffuser area, 1/3 the flow rate per unit area of diffuser

- BUT, alpha did not change significantly; stayed ~ 0.3 at head end of plug flow; did not measure a significant efficiency increase
  - If clean water efficiencies would be 36% versus 30% for the ceramics, difference in alpha SOTE 10.8% versus 9%

- The pressure drop through the diffusers was higher than through the 30 year old ceramics – frequent “bumping” is likely required with membrane tubes

- May consider membrane discs up front in a plug flow system and the dense diffuser placement in later stages
What about Ceramic Plugging?

- Ceramics- 32 yrs in Madison and no noticeable loss in SOTE, but what about plugging?
- UW Research – Scale Develops into top 1-10 mm; lower diffuser flux rate, deeper penetration
- Both inorganic and organic scale
- Power outages exacerbate the problem
- Seemed to be CaPO4 scale from scanning electron micrograph
- HCl cleaning did not seem to remove the inorganic scaling
- Increased to a minimum ceramic rate of 0.9 cfm/diffuser rather than 0.5 and installed pneumatic valves to prevent backflow in power outages and blower failures
D.O. and Air Flow Control

- As shown, minimizing D.O.'s essential to energy conservation
- Air flow to tank can be controlled by D.O., ammonia, or ORP, but the key to efficient oxygen transfer is to keep the D.O. low
- Blower & Diffuser turndown limited in Madison
West Plant Aeration Blowers

- Blower 1: COMP AUTO 732 kW
- Blower 2: LOC AUTO 0 kW
- Blower 3: LOC MIN 0 kW

Bypass Valve #1: SP 41% Open PV 42% Open
Bypass Valve #2: SP 25% Open PV 25% Open
Bypass Valve #3: SP 24% Open PV 24% Open

Air Pressure Header: SP 8.3 PSI PV 8.3 PSI

West Bleed Valves:
- AT 21: AUTO
- AT 24: AUTO
- AT 25: AUTO
- AT 28: AUTO

48% = Max Guidevane Position
24% = Min Guidevane Position

17,088 CFM To West Nit Tanks
Aeration Costs for Various Blower Efficiencies and Oxygen Transfer Efficiencies

Energy Use Per 1000 Lbs of Oxygen Delivered (kw-hr/1000 lbs)

- Blower Efficiency
  - 20 cfm/kw
  - 25 cfm/kw
  - 30 cfm/kw
  - 35 cfm/kw

Field Diffuser Oxygen Transfer Efficiency

6% 8% 10% 12% 14% 16% 18% 20% 22% 24%
Operation @ D.O. = 2.0 would save $150,000/yr
Operation @ D.O. = 0.5 would save $300,000/yr
Other Process Factors affecting Energy Use

- SRT Control
- Nitrogen/denitrification and phosphorus removal
- Nitrite Shunt, Anammox, Denitrifying PAO’s
- Conventional Denitrification Options
Weighted Avg alpha Increased with Increasing SRT
SRT Effect

- Transition from non-nitrifying plant to nitrifying – the increase in transfer efficiency paid for the additional nitrogenous oxygen demand
- The SRT effect is well documented in the EPA, “Fine Pore Aeration Design Manual”
- What about nitrification/denitrification to save $$?
Nitrification/Denitrification

Autotrophic Bacteria
Aerobic Environment

- 1 mole Ammonia (NH₃/NH₄⁺)
- 25% O₂ (energy)
- 75% O₂ (energy)
- ~100% Alkalinity

Heterotrophic Bacteria
Anoxic Environment

- 1 mole Nitrite (NO₂⁻)
- 40% Carbon (BOD)
- 60% Carbon (BOD)
- 1/2 mol Nitrogen Gas (N₂)

Nitrification

Denitrification

Nitrite Oxidizing Bacteria (NOB)

Ammonia Oxidizing Bacteria (AOB)
Nitrite Shunt

Autotrophic Bacteria
Aerobic Environment

- 75% O₂ (energy)
- ~100% Alkalinity
- 1 mole Nitrite (NO₂⁻)
- 1 mole Ammonia (NH₃/NH₄⁺)

Ammonia Oxidizing Bacteria (AOB)

Nitritation

Heterotrophic Bacteria
Anoxic Environment

- 1 mole Nitrite (NO₂⁻)
- 60% Carbon (BOD)
- 1/2 mol Nitrogen Gas (N₂)

Denitritation
Anaerobic Ammonia Oxidation -- Anammox
Carbon Requirement is Key

- If enough carbon for complete nit/denit (and phosphorus removal for Bio-P), external oxygen requirement is the same for all nitrogen removal options.

- In spite of competition for carbon, Bio-P may benefit nitrification/denitrification.
  - Anaerobic selector prevents filaments.
  - Since filaments no problem even at 1.0 mg/l D.O.:
    - Different nitrifiers adapted to low D.O. operation in UW studies with MMSD -- both in pilot plants and full scale.
    - PAO’s still did good job at phosphorus uptake.
    - Simultaneous nit/denit likely occurring with low D.O.’s.
Without Selector – Safe D.O. versus F:M ratio

- Bulking occurred
- Bulking did not occur

F/M, kg COD removed/kg MLVSS, d

Aeration basin DO, mg/L

“Safe” operating line

DO uptake rate, mg O₂/g VSS, h⁻¹
St. Petersburg Approach

- Nitrite Shunt Operation, No Recycle Streams Required; both effluent N&P are very low
- Ammonia control of aeration
- SRT closely controlled to as low of a setpoint as possible
- Configuration similar to AO configuration
Hampton Roads Approach

- Not using Bio-P for phosphorus removal
More Conventional Options

- Conventional Options to Optimize Denitrification and still obtain P removal using available carbon
  - Based on MMSD/UW studies D.O. operation with low D.O.’s (<=1.0 mg/l) possible with conventional configurations
  - A2O with low D.O. operation
  - 5-Stage Bardenpho with low D.O. operation
- Both options have an extra recycle pumping stream
A2O w/ Low D.O. Operation
(~5-10 mg/l TN)
5-Stage Bardenpho
(\(\sim 3-6 \ \text{TN}\))
Use Previous Graph to Compare Energy Use
Example Calcs

Secondary Energy Use for a 20 MGD Plant With Nitrogen and Phosphorus Removal
Alpha SOTE=16%, To 2ndary -- BOD=140, TKN=28
Recycle Flow = 150% for A2O and UCT
Summary Observations

- Nitrite shunt and anammox – new processes with design and control parameters still being defined; what about cold temperature operation and will operation affect alpha SOTE?

- Conventional options include recycle pumping but with low D.O. operation and efficient blower design could be huuuge energy savings options

- Process options should be considered with effluent limitations, but energy use is most simply reduced with:
  - Fine bubble diffusers
  - Controlling D.O.’s to low setpoints
  - Efficient blowers
Mixing

- Madison anaerobic/anoxic zones
  - NR 110 0.6 hp/1000 cf for mechanical mixing
  - Original design 0.4 hp/1000 cf; no screening, poor grit removal
  - Revised 0.13 hp/1000 cf; fine screening, new grit removal

- Madison fine bubble diffusers
  - NR 110 20 cfm/1000 cf
  - 3rd pass, minimum is ~10 cfm/1000 cf, 0.17 cfm/sf
  - Fine bubble minimum ~0.12 cfm/sf (EDI Technical Bulletin)
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