Energy Matters in WWTP’s

Steve Reusser, 02/18/2016
Effluent is Important; but It Takes a Lot of Energy; How to Conserve?
Areas of Opportunity

- VFD’s and Hi Efficiency Motors for pumping processes such as RAS and WAS
- Secondary Treatment Energy Use -- Aeration usually uses 40–50% of energy at a plant
- Anaerobic Digestion Gas Utilization -- 20 to 100% of energy used can be recovered through gas utilization
- Disinfection Energy Use
Aeration Savings Opportunities

- Blowers
- Diffusers
- Air Flow and D.O. Control
Blower Design
Blower Types & Drives

- **Centrifugal** Single-stage or Multi-stage
  - Variable Speed
  - Constant speed with inlet throttling
- **Positive Displacement**
  - Variable Speed
  - Two-speed motors
- **Hi Speed Turbo**
  - Variable Speed
Single Stage Centrifugal Blower w/ Inlet Guide Vane Saving Energy

~7,000 rpm
Single Stage Efficiency

![Graph showing Air Flow and Efficiency vs Guide Vane Position](image)
Multi-Stage Centrifugal Blower
Throttle Inlet Valve or Vary Speed
Positive Displacement Blower
Turbo Blower since 2005, Developed by NASA

- ~60,000 rpm
Hi Speed Turbo Blower Air Foil Bearing (Also Magnetic Bearings Available)
Neuros Turbo Blower vs Roots PD in Franklin, NH
High-Speed Turbo Blowers

- Many companies now offer options:
  - Neuros
  - Siemens (Turblex)
  - Aerzen
  - Hoffman
  - HSI
  - ABS
  - Atlas Copco
## 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>

** Testing methods not consistent
Relative Blower Efficiencies (+or– for ~15’ deep tank)

- PD Blowers 25–28 cfm/kw
- Single or Multi-Stage Centrifugal with inlet throttling 20–33 cfm/kw (depending on inlet throttling ratio)
- Hi Speed Turbo blowers 35 cfm/kw
Other Pluses & Minuses

- Controls on single stage centrifugal and high-speed turbo are more difficult to tune and are more susceptible to surge; blower and VFD selection DESIGN CRITICAL; must be based on aeration system characteristics
- Over-pressurization on a PD blower can damage blower; pressure relief is important; less efficient at lower flows and higher pressures; maintenance, though, is simpler
Diffuser Design
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
- **Saturation Concentration**: ~10.6 mg/l depending on tank depth
- **Field OTE**: Transfer efficiency at actual D.O. in dirty water – the bottom line
Diffuser Efficiency Factors

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

- Process Operation – 1) Long SRT vs. short SRT,
  2) Plug flow vs. complete mix or step feed,
  3) Strength of Waste

- Flux Rates
- Dissolved Oxygen Levels
Diffuser Types

- Domes
- Coarse Bubble
- Ceramics
- Membrane or Ceramic Tubes for Coarse Bubble Replacement
- Membrane
- Sanitaire Gold Series Test Diffusers
Diffuser Efficiency and Flux Rate

- 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 re-searched 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 aerator devices are limited. Alpha values of 0.23 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 limited value.
Fine Bubble Performance Improves with Increasing SRT

![Graph showing Sludge Age and Alpha SOTE vs Time](image)
How Do You Test Efficiency?
Off-Gas Testing
Madison Example

FIGURE 1
MADISON PROCESS SCHEMATIC

An aerobic tank train consists of two 3-pass aeration tank trains and 4 clarifiers.
Volume each train:
- 0.5 MG -- Anaerobic
- 0.17 MG -- Anoxic
- 2.33 MG -- Aerobic
- 3.00 MG -- Total
Volume each clarifier: 1.00 MG
Typical Ceramic Data Standard Transfer Efficiencies

FIGURE 6
Alpha SOTE's During 2002 Off-Gas Testing

- SOTE P11 7/10 (Normal Ops, Lo DO's)
- SOTE P114 7/15 (Normal Ops, Hi DO's)
- SOTE P114 8/28 (Test, Lo DO's)
- SOTE P114 11/6 (Test, Step Feed, Lo DO's)
Influences on Alpha

**FIGURE 5**
Tank Position vs Alpha

- alpha Phi 7/10 (Normal Ops, Lo DO's)
- alpha Phi 7/15 (Normal Ops, Hi DO's)
- alpha Phi 8/26 (Test, Lo DO's)
- alpha Phi 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 PIH3 7/10, 14.74% Wtd (Normal Ops, Lo DO's)
- FOTE PIH4 7/15, 10.87% Wtd (Normal Ops, Hi DO's)
- FOTE PIH4 8/28, 16.64% Wtd (Test, Lo DO's)
- FOTE PIH4 11/6, 14.50% Wtd (Test, Step Feed, Lo DO's)
Results from Testing

- Limited turndown, hi D.O.’s, 10.87% FOTE, 40% wasted air
- Step Feed & low D.O.’s 14.50% FOTE vs. 16.64% Plug Flow and low D.O.’s because of depressed alpha
- Regular, well designed operation, 14.74% FOTE (D.O.’s rise quickly near the end of the tank)
Ceramic Diffusers in Madison
Madison Membrane Test Layout
Off Gas Testing – Test Results

- The transfer efficiency improved because of lower flux rate and increased density– 3X as much diffuser area, 1/3 the flow rate per square foot of diffuser
- Alpha did not change significantly
- Oxygen Demand is satisfied more quickly
- D.O. must be controlled to effect savings
- The pressure drop through the diffusers was higher than through the 30 year old ceramics – frequent “bumping” is likely required with membranes
What about Ceramic Plugging

- UW Research – Scale Develops into top 1–10 mm; lower diffuser flux rate, deeper penetration
- Both inorganic and organic scale
- Power outages may exacerbate the problem
- Seemed to be CaPO4 scale from scanning electron micrograph
- HCl cleaning did not seem to remove the inorganic scaling
- Used a minimum ceramic rate of 0.9 cfm/diffuser rather than 0.5
Factors in Diffuser Selection and Design

- Efficiency and first cost
- Diffuser Life Expectancy: 30+ years for ceramics, 10–15 years for membranes
- Tendency for ceramics to plug – In current test, though, air was throttled in ceramic grids to force enough air through membranes
- Cleaning requirements – Madison cleans ceramics about every 4 years with hosing and dilute HCl dosing on surface
- Minimum diffuser flow and minimum blower turndown must match – surge or over-pressurization could result
Air Flow & D.O. Control
D.O. and Air Flow Control

- As shown, minimizing high D.O.’s essential to energy conservation
- Air flow to tank can be used to control D.O. – can either be directly by blower control or air flow control valve on tank
- Air valves need to be kept as open as possible to minimize pressure, prevent surge, and save energy (most open valve programming often used if more than one tank)
Air Flow Control Valve
The Bottom Line on Aeration
From a UW–Madison Thesis

For the Madison MSD:
Operation @ D.O. = 2.0 would save $150,000/yr
Operation @ D.O. = 0.5 would save $300,000/yr

Figure 3.12 Full-scale Nine Springs WWTP percent aeration energy reductions for 9 different dissolved oxygen scenarios
Aeration Costs for Various Blower Efficiencies and Oxygen Transfer Efficiencies

Coarse bubble, PD blower, 2.0 mg/l D.O.

Fine bubble, hi speed turbo, 2.0 mg/l D.O.
Total Savings

- 1/5 the energy used for fine bubble diffuser system with hi efficiency blower and D.O. control
- If D.O. is not controlled, substantial savings are sacrificed
Digester Gas Utilization
Digester Gas Utilization, Collection & Treatment

- Reciprocating Engines (25–40% efficient)
- Microturbines (30–40% efficient)
- Tubines (30–40% efficient)
- Fuel Cell (40–50% efficient)
- CNG for Vehicle fuel
- Low pressure storage or Hi pressure Storage sphere needed to smooth out variability of production
Gas Collection and Treatment

- Gas supply needs to be reliable
- Gas treatment may include:
  - Gas drying
  - H2S removal
  - Siloxane removal
  - Carbon dioxide scrubbing
Gas Collection & Treatment (cont)

- Siloxanes from personal care products
- Siloxanes have increased in concentration over the last few years.
- Siloxanes leave silica deposits in piston, sleeves, boiler tubes
- Hydrogen sulfide can also cause problems. Concentrations >200 ppm typical
- Moisture in gas increases both siloxanes and hydrogen sulfide
Storage could be high pressure sphere or membrane cover or floating steel cover (shown)
Heat Recovery

- Heat Recovery is Important for cost-effectiveness; cannot compete with utility just for electrical generation
Internal Engine Loop -- Glycol
Treatment System Operation

Changing media in one siloxane vessel and H2S vessel every 12–18 months.

Costs for Madison treating ~32,000 cfh:
$14,000/year for H2S iron sponge media
$45,000/year for siloxane media in one of the two tanks

Has reduced engine maintenance significantly
Inside versus outside location a “hot” topic for northern climate
Opportunities to Increase Energy Production

- Improve waste activated sludge digestion
  - Cell lysing technologies
  - Advanced Digestion processes (thermophilic or TPAD)
- Recruiting High Strength Wastes
  - Grease
  - Whey
  - Food Waste

Madison received 25,000 gpd of whey for almost 15 years and increased gas production/energy production ~ 20%. Currently funding a UW study looking at food waste compatibility in the digesters.
Disinfection
Disinfection Costs

- Chlorine versus Ultraviolet -- Usually must dechlorinate; safety issues
- Low Pressure versus Medium Pressure UV – much less capital cost and area required for medium pressure, but low pressure options are more energy efficient
- Madison has operated two generations of low pressure systems since 1985
Comparison with Data from Pacific Gas & Electric in California

Power Use (Kwhr/MG)

- Energy for making Chlorine for 10 mg/l dose
- CA plants with medium press
- CA two small plants w/ lo press
- CA 43 MGD plant, lo press
- Madison Original system
- Madison 42 MGD, lo press

0 100 200 300 400 500 600
UV Operational Notes

- System is flow paced – banks are added and removed by influent flow
- Tried intensity sensors – not worth maintaining with little variability in effluent quality
- Quartz tubes have not need cleaning during disinfection season for generation 2 system – coincides with startup of biological phosphorus removal
Questions?

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