Tennessee Water Wastewater Utility Partnership

Aeration Efficiency and Optimization

Lee E. Ferrell, P.E., BCEE, CEM, LEED Green Assoc.

Make the most of your energy™
Aeration in Water Wastewater
WWW Challenges: Drivers/Trends

- **Demand** for WWW
- **Age** of infrastructure
- **Legislative compliance**
- **Reduced financial** resources
- **Energy efficiency awareness**
- **Energy use**

Typical wastewater process energy usage breakdown:

- **Pumping** = 87%
- **Process** = 91.9%

**Typical water process energy usage breakdown**:

- Distribution Pumping: 67%
- Treatment Process: 11%
- Raw Water Pumping: 11%
- In-plant Pumping: 9%
- Lighting & Buildings: 2%

**Typical wastewater process energy usage breakdown**:

- Aeration: 54.1%
- Collection: 14.3%
- Anaerobic Digestion: 14.2%
- Lighting and Buildings: 3.9%
- Belt Press: 3.2%
- Clarifiers: 1.4%
- Grit: 0.5%
- RAS: 0.3%
- Chlorination: 0.1%
- Gravity Thickening: 0.3%
Water energy use

71% of consumed electricity is used to turn motors

65% of this energy is used for fluid applications

Wastewater energy use
Aeration System Overview and Fundamentals
Overview

● The blower system:

**Components**
- Blower
- Motors, engines
- Piping
- Valves and fittings
- Controls and instruments
- Heat exchangers
- Tanks
- Others

**End-use**
- Water treatment
- Wastewater treatment
- Water distribution
- Power generation
- Irrigation
Overview, continued

**System Approach**

- **Component** optimization involves segregating components and analyzing in isolation
- **System** optimization involves studying how the group functions as one as well as how changing one component can help the efficiency of another
Control Systems for Total Value

- Dissolved Oxygen (DO) Control to Minimize Air Flow
- Blower Control to Optimize Efficiency
- Direct Flow Control and Most Open Valve Control to Minimize Pressure
- Blower Protection to Maintain Your Investment
DO Control Fundamentals

It’s all about the bubbles!
Aeration Energy

- Mechanical Aerators
- VFD Reduces Energy
- Challenge:
  - Limit due to suspension of solids
- Install submersed mixers
  - Low Aerator speed saves energy
    - Mixer energy may be less than savings
  - Not needed at high aeration
Jet or Diffused Air

- Energy reduction via:
  - Basin/Zone air control
  - Blower control

- Challenge
  - Air used to mix water

- Blower efficiency only as good as air distribution
DO Control Fundamentals

- Air is supplied to aeration basins in suspended growth diffused air processes to provide oxygen needed to maintain biological activity in the aeration basins.

- Oxygen required is basically proportional to organic loading – both BOD$_5$ reduction and Nitrification.

- Air also provides mixing to keep the bacteria suspended and aids in flocculation.
DO Control Fundamentals

Aeration Control System Objectives:

- Satisfy the Oxygen Demand of the Treatment Process
- Achieve Process Requirements at the lowest possible cost
DO Control Fundamentals

- DO (Dissolved Oxygen) concentration is an indirect indicator of proper air flow to the process

- “Normal” DO concentration means the process is not oxygen limited
  - If you have very low or zero DO you cannot have adequate process performance
  - You can have high DO and not have adequate process performance
  - Most operators set DO concentration too high
    - Typical 2.0 BOD – can be as low as 1.0
    - Typical 3.0 Nitrification – can be as low as 1.0
    - If BNR use as low as possible to avoid “oxygen poisoning
DO Control Fundamentals

- Low DO can cause undesirable organisms to develop

- High DO can cause poor settling, undesirable organisms to develop

- Excess DO does always not result in more biological activity
  - Bugs don’t work twice as hard at 4.0 ppm DO than they do at 2.0 ppm DO

- High DO just wastes power
DO Control Fundamentals
DO Control Fundamentals

• $O_2$ for $BOD_5$ Reduction:

\[
\text{Required } O_2 \text{ for BOD} = 1.1 \cdot \frac{LbO_2}{Lb_{BOD}}
\]

• $O_2$ for Nitrification ($NH_3$ to $NO_3$):

\[
\text{Required } O_2 \text{ for Nitrification} = 4.6 \cdot \frac{LbO_2}{Lb_{NH_3}}
\]

In BNR systems denitrification typically recovers 25% of $O_2$ used for nitrification.
DO Control Fundamentals

Total Air Flow Required:

\[ SCFM = \frac{0.335 \cdot \text{mgd}}{\text{OTE}} \cdot \left( \text{ppm} \text{BOD}_{\text{removed}} 1.1 + \text{ppm} \text{NH}_3_{\text{converted}} 4.6 \right) \]

- \text{mgd} = \text{Wastewater flow rate, million gallons per day}

- \text{SCFM} = \text{Air Flow Rate, Standard Cubic Feet per Minute (68°F, 14.7 psia, 36% RH)}

- \text{OTE} = \text{Actual Oxygen Transfer Efficiency, Site Conditions}

OTE is not a constant!
DO Control Fundamentals

Oxygen Demand Varies in Time from Diurnal Variations

Ratio of Peak to Minimum Flow is Typically 2:1
OTE and DO Control

- When load increases at a constant air flow DO concentration drops
- Concentration does not drop to zero because OTE changes and may compensate for increased loading
- OTE is NOT a constant!
OTE and DO Control

OTE Varies with Air Flow per Diffuser
OTE and DO Control

OTE Varies with DO Concentration:

![OTE Variation with DO](chart.png)

OT...
OTE and DO Control

At steady state the Oxygen Transfer Rate (OTR) demanded by the process is equal to the OTR provided by the aeration system. When this is not true, the process is not steady state and the DO concentration changes until a new equilibrium is established at new steady state conditions.

\[
\text{OTE} \times \text{SCFM} \times \rho_{\text{air}} \times \%O_2 = \text{OTR} = \text{OUR} \times \text{Tank Volume}
\]
OTE and DO Control
Response of DO to 20% Load Increase
Starting at 3.0 ppm DO

1) Initial operation at 50 kg/hr OTR, 2 SCFM per diffuser, 3.0 ppm DO
2) 20% load increase to 60 kg/hr OTR, 2 SCFM per diffuser, DO drops to 1.3 ppm
3) Operation at 60 kg/hr OTR, air flow increases to 2.5 SCFM per diffuser, restore 3.0 ppm DO

25% flow change required to correct 20% load change!
DO Control

DO Control Operation:

- Establish Targets (Setpoints)

- Response to Deviations from Targets:
  - If DO > Setpoint reduce oxygen supply
  - If DO < Setpoint increase oxygen supply

- Control basin and blower air flow
DO Control

- Automatic DO Control will save 25% to 40% of Aeration System Energy Compared to Manual Control
DO Control

Savings Proportional to Driving Force of $O_2$

Increased System Complexity Must Be Justified by Increased Savings

- Group Basin DO Control

- Individual Basin DO and Air Flow Control with Most-Open-Valve (MOV)

- Individual Zone DO and Flow Control for Each Basin
Basic Control System
Blower Control Concepts

Once the Optimum Aeration System Air Flow Has Been Determined It Is Necessary to Provide the Correct Flow From the Blowers

- The Purpose of Blower Control is to Provide the Correct Air Flow

- Process Requires Controlled Mass Flow Rate

- Control Technique Varies With Type of Blower
Positive Displacement (PD)
- Constant flow at constant speed
- Pressure varies with system requirements
- Use VFDs (Variable Frequency Drives) to modulate air flow
- Power consumption directly proportional to flow and pressure
Blower Control Concepts

**Graph 1:**
- **BHP @ Constant Pressure**
- **BLOWER SPEED (RPM)**
- **Performance**
- **Design**

**Graph 2:**
- **ICFM**
- **BLOWER SPEED (RPM)**
- **Performance**
- **Design**
Blower Control Concepts

Multistage Centrifugal

- Variable flow at Approximately Constant Pressure
- Usually controlled by inlet throttling to modulate flow
- VFDs to modulate air flow will improve efficiency and turndown (with appropriate curves)
Blower Control Concepts

![Graph showing Blower Control Concepts]
Blower Control Concepts

Single Stage Centrifugal

- Variable flow
- Pressure varies with load
- High efficiency
- Most common > 500 hp
- Inlet Guide Vanes and/or Variable Discharge Diffusers to modulate flow and improve turndown
Blower Control Concepts - IGV
Blower Control Concepts – Variable DDV
Blower Control Concepts

Dual Vane Operation Maintains Efficiency

- MIN IGV and DDV Position
- MAX IGV and DDV OPENING
- BEP

% MASS FLOW RATE vs. % GAUGE PRESSURE graph
Blower Control Concepts

Evaluate Total Blower Performance

- Equipment Cost
- Installation Cost
- Maintenance Cost
- ENERGY COST
Blower Energy Evaluation

- Use realistic inlet conditions
  - Average temperature and pressure
  - Include inlet losses

- Use expected range of operating air flow
  - The Blower With the Highest Design Point Efficiency May Not Provide Lowest Power Consumption

- Include control system characteristics in evaluation
- Determine if energy payback justifies higher initial investment
Manual Diffused Air Control Scheme

- **Advantages**
  - Economical Construction

- **Disadvantages**
  - Energy Intensive
  - Efficiency = Continual adjustment

- **Solution**
  - Motor Starters/RVSS
Average Diffused Air Control Scheme

- Average Basin DO controls blowers

- Advantages
  - Less operator intensive than manual
  - Economical construction compared to automatic distribution

- Disadvantages
  - Rough control = Energy Intensive
  - “Goldilocks effect”

- Solution
  - Motor Starters/RVSS
  - PLC for blower control
Basin Control Schemes

- Each Basin Controls DO
  - Flow to each basin measured
  - Blowers adjusted to meet total demand

- Advantages
  - More accurate control
  - Manual observation eliminated

- Disadvantages
  - Inter-basin DO variation

- Solution
  - Motor Starters / RVSS
  - PLC for Basin and Blower Control
Multi Zone Control Scheme

- Each zone controls its DO

- Advantages
  - Greatest energy savings
  - No/Low operator intervention
  - Minimize inter-basin DO variation

- Disadvantages
  - Most expensive to construct
  - Energy Savings / Process Stability Tradeoff

- Solution
  - Motor starters/RVSS
  - PLC
    - Basin valve control
    - Blower inlet valve control
• **Inlet Throttling**
  - Traditional method
  - Inlet Valve controls air volume
  - Fixed speed
    - Fixed curve
    - Surge is at fixed power/amperage
  - Surge done through:
    - Current meter
    - Power meter
VFD Based Blower Control

● Better energy savings than inlet throttling valve
● But with limits
● Must design differently
Affinity Laws

Effects centrifugal pumps and blowers under different rules

P.D. Blowers finds impact of varying speed

On Flow Pressure & Power

Flow Changes Proportionally

Q1/Q2 = S1/S2

Pressure Changes By the Square

H1/H2 = (S1/S2)^2

Power Changes By the Cube

P1/P2 = (S1/S2)^3
Inlet Throttling

- Curve sized for 60 Hertz
- Throttled to meet demand
- Surge Control via power or current meters

- Curve sized for 80% operating time
- Full Speed
  - ~ 10% of the time
  - Accept Power & Pressure rise
- Surge control algorithm with flow
Blower Energy Evaluation

![Graph showing typical diurnal flow with time of day (12:00 AM, 04:00 AM, 08:00 AM, 12:00 PM, 04:00 PM, 08:00 PM, 12:00 AM) and percentage of average (0%, 50%, 100%, 150%)]
Flow Control Basics

- DO concentration depends on air flow, **NOT** on Pressure

- Blowers create air flow, not pressure

- The system creates pressure through resistance to air flow
Flow Control Basics

What is operating point?
Flow Control Basics

The System Curve identifies the relationship between flow and back pressure (resistance to flow)
Flow Control Basics

Combining the System Curve and the Blower Curve defines the actual operating air flow.

**Typical Centrifugal Blower & System Curves**

- **Blower Curve**
- **Operating Point**
- **System Curve**
- **Static Pressure**

![Graph showing typical centrifugal blower system curves with pressure on the y-axis and flow on the x-axis.](image-url)
Pressure Control Basics

DO is not a function of system pressure. DO control requires control of air flow only.

Blower control means modulating air flow rates.

Pressure control is designed to minimize interference between basins and to coordinate blower output and basin air flow demand.

Use of direct flow control and MOV logic to reduce pressure and power
Pressure Control

Excess Pressure Simply Wastes Power
Pressure Control

Pressure control has a number of problems:

Problems with Pressure Control:

- **Instability**
  - Basin and blower control loops “fight” each other
  - Difficulties operating at extremes of blower capacity
  - Interactions with multiple basins

- **Tuning difficulties and re-tuning requirements**
  - Inherent PID tuning complications
  - One blower vs. two blowers running
  - Night vs. day operation

- **Wasted power – 10% or more**
Direct Flow Control
Direct Flow Control

- Basin Air Flow Control Saves Power Because “Identical” Basins Don’t Perform Identically
  - Variations Due to Influent Channels
  - Variations Due to RAS
  - Variations Due to Air Piping and Manual Valve Adjustments

- Direct Flow Control Approach
  - Summation of basin flow requirements = total blower flow
  - Δ flow, not absolute setpoint
  - Modulate blowers into safe operating range
Direct Flow Control

- Eliminates need for pressure control to save power and energy cost
- Totalize changes in air flow for tanks and modulate blowers air flow accordingly
- Integrate air flow control at BOTH ends of air piping
Most-Open-Valve Control Concepts

- Excess blower discharge pressure wastes power

- Operators tend to set pressure setpoint too high – often 1 to 1.5 psig above requirement

- Optimum energy use is achieved when the pressure in the header is just enough to overcome static pressure plus friction loss through the worst case diffuser header

- Most-Open-Valve Control is a technique for power minimization, not a blower control or DO control technique
Most-Open-Valve Control Concepts

Impact of excess pressure on blower power:

- PD blowers: very significant
- Inlet throttled multi-stage centrifugals: minor
- Inlet guide vane controlled single-stage or multi-stage centrifugals: significant
- VFD controlled multi-stage centrifugals: very significant
Most-Open-Valve Control Concepts

- Most-Open-Valve (MOV) implies that one basin air flow control valve is at maximum position to minimize system pressure.
- MOV logic is independent of blower control logic.
- Older style pressure control based systems typically use a changing pressure setpoint based on valve positions.
# Energy Efficiency in Pumps and Blowers

- **Load Characteristics**

## Water Wastewater Load Characteristics

<table>
<thead>
<tr>
<th>Torque Type</th>
<th>Typical Applications</th>
<th>Energy Savings Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable Torque</td>
<td>Centrifugal Pumps and Blowers</td>
<td>Substantial Potential – Largest of all VFD applications</td>
</tr>
<tr>
<td>Constant Torque</td>
<td>Positive Displacement Pumps, Blowers, Mixers, and Chemical Feed Pumps</td>
<td>Lowest Potential</td>
</tr>
<tr>
<td>Constant Power</td>
<td>No applications</td>
<td>No Potential</td>
</tr>
</tbody>
</table>

---

**The Main Target (first priority)**

**The Next Step (second priority)**

---

![Graph showing energy savings (%) vs. Speed (%)](attachment://graph.png)
VFD Benefits with Blowers
VFD Benefits with Pumps

- Physical Laws for Centrifugal Loads

**Its Pure Physics:** Due to the laws that govern centrifugal pumps, the flow of water decreases directly with pump speed

**Affinity laws of centrifugal loads:**

\[
\text{Flow} = f(\text{motor speed})
\]

\[
\text{Pressure} = f(\text{motor speed})^2
\]

\[
\text{Power} = f(\text{motor speed})^3
\]
VFD Benefits with Pumps

• Physical Laws for Centrifugal Loads

A motor running at 80% of full speed requires 51% of the electricity of a motor running at full speed.

\[ (.8 \times .8 \times .8 = .512) \]
VFD Benefits with Pumps

• Physical Laws for Centrifugal Loads

A motor running at 50% of full speed requires 12.5% of the electricity of a motor running at full speed.

\((0.5 \times 0.5 \times 0.5 = 0.125)\)
Aeration Efficiency and Optimization
Efficiency of Blower Systems

• Equations for efficiency

Blower Energy Usage

\[ kW = \frac{0.011503 \times (Q \times p_i \times X)}{(\eta_{Motor} \times \eta_{Blower} \times \eta_{Drive})} \]

Q = Blower inlet volumetric flowrate, ICFM
\( p_i \) = Blower inlet pressure, psia
\( \eta \) = efficiency
X = Blower adiabatic factor
\[ X = \left( \frac{p_d}{p_i} \right)^{0.283} - 1 \]
\( p_d \) = Blower discharge pressure, psia
\( p_i \) = Blower inlet pressure, psia

Blower Efficiency Measurement

\[ \frac{kW}{MGD} = \frac{kW}{Q} \]

\[ \eta_{Motor} \times \eta_{Blower} \times \eta_{Drive} = \frac{(Q \times p_i \times X)}{(0.011503 \times kW)} \]

\[ \eta_{Wire\ to\ air} = \frac{(Q \times p_i \times X)}{(0.011503 \times kW)} \]
Blower Energy Optimization is Complex

• Simple Guidelines for reducing energy usage
  
  ➢ Match blower airflow to the process requirements
  ➢ Minimize system discharge pressure and inlet losses
  ➢ Provide flexibility and adequate turndown for loading variations
VFD Benefits with Blowers

• Other Benefits

In addition to Energy Saving, using a VFD has many other advantages:

• Less mechanical stress on motor and system
• Less mechanical devices - Less Maintenance
• Process regulation with PID regulators, load management functions
• Reduce noise, resonance avoidance
• Performance and flexibility, range settings, above base operations
• Easier installation and settings, drive mechanics
• Can be controlled with Automation, Communication networks
Process Energy Optimization

Automation is the Key

- Develop consistent and appropriate milestone and deliverable expectations
- Standardize program schedule tracking requirements
- Establish key energy management performance metrics
- Produce meaningful reports that allow for clear and concise decision-making
- Install additional monitoring equipment as needed
Benchmarking and Key Performance Indicators
Possible Benchmarking KPIs

- kWh/MG
- kWh/OTR
- kWh/lb BOD Removed
- kWh/TSS Removed
Thank you for your time

Lee E Ferrell, P.E., BCEE
Schneider Electric Water Wastewater Competency Center
864-784-1002
lee.ferrell@us.schneider-electric.com
http://www.schneider-electric.us/solutions/water-wastewater/