Better Plants
U.S. DEPARTMENT OF ENERGY

Biological Wastewater Treatment Training Series
Presentation #11: Aeration Systems

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U.S. DEPARTMENT OF ENERGY

Aeration Systems

References: Metcalf & Eddy, 4th edition
Water Environment Federation: Activated Sludge Process Control

OUTLINE

- Energy Use in WWTPs
- Diffused Aeration Systems
- Measuring Performance of Diffused Aeration
- Energy Conservation Measures with Diffused Aeration Systems
- Mechanical (Surface) Aeration
- Measuring Performance of Surface Aeration
- Energy Conservation Measures with Surface Aerators

Energy Use in WWTPs

- Aeration typically consumes 25% to 60% of total plant energy use.
- Aeration systems must be designed and operated to match actual oxygen demands.
- Aeration systems must have flexibility to respond to changing real-time oxygen demands efficiently.

Types of Aeration Systems

- Diffused aeration
- Mechanical surface aeration
- Hybrid Systems
  - Jet systems
  - U-tube aerators
  - Submerged turbine aerators

Diffused Aeration Systems

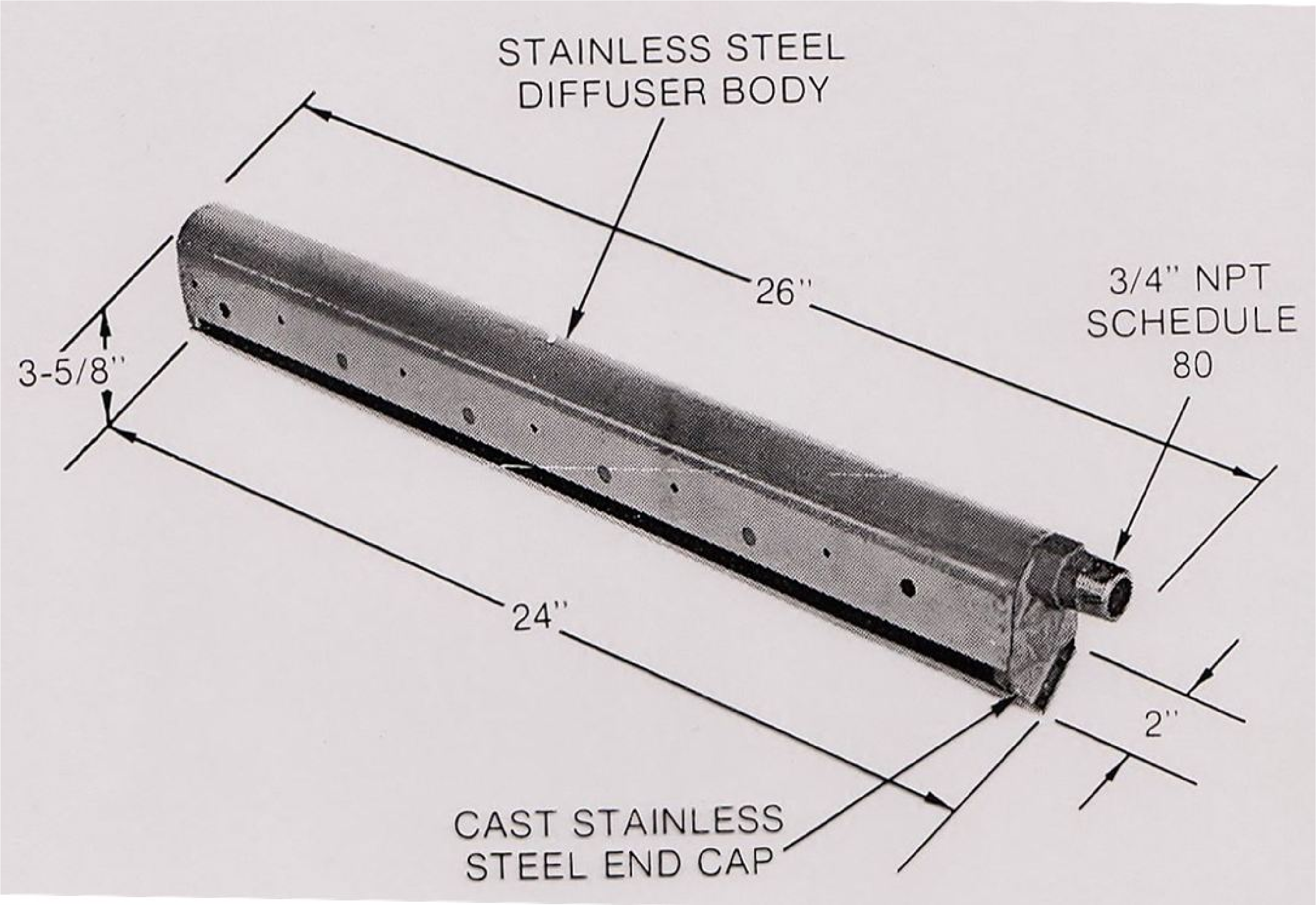
- Major components of diffused aeration systems:
  - air intake system
  - blowers
  - air piping system
  - diffusers
  - controls

Biological Reactor with Aerated Mixed Liquor (diffused aeration)

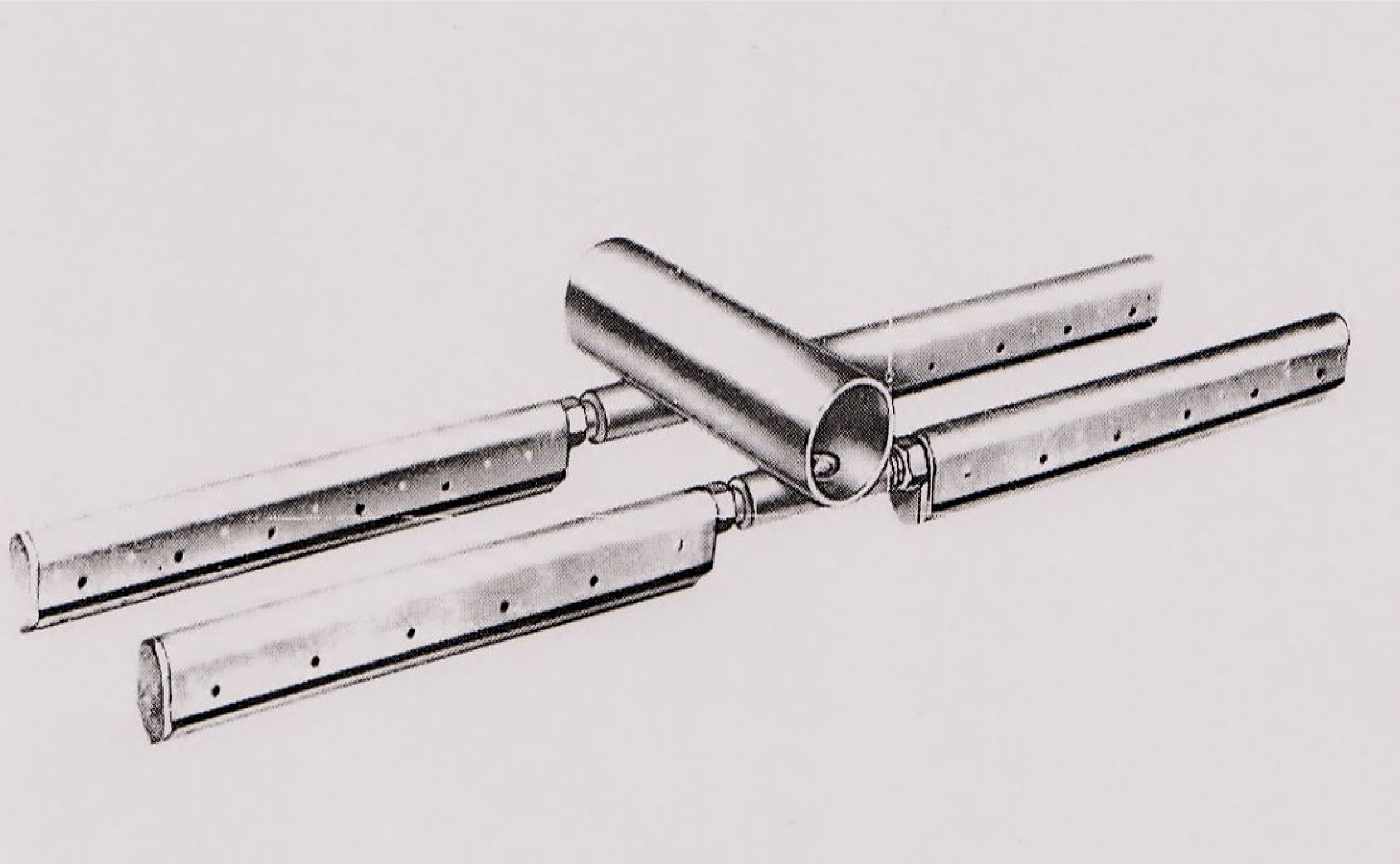
Configuration of Diffusers

- Use plug-flow basins
- Use tapered aeration to reduce the rate of oxygen supply along the length of a basin
- Place more diffusers at inlet and decrease the number of diffusers along the basin's length
- Do not operate fine bubble diffusers in excess of the diffusers' maximum air flow rate (may produce coarse bubbles & reduce OTE)

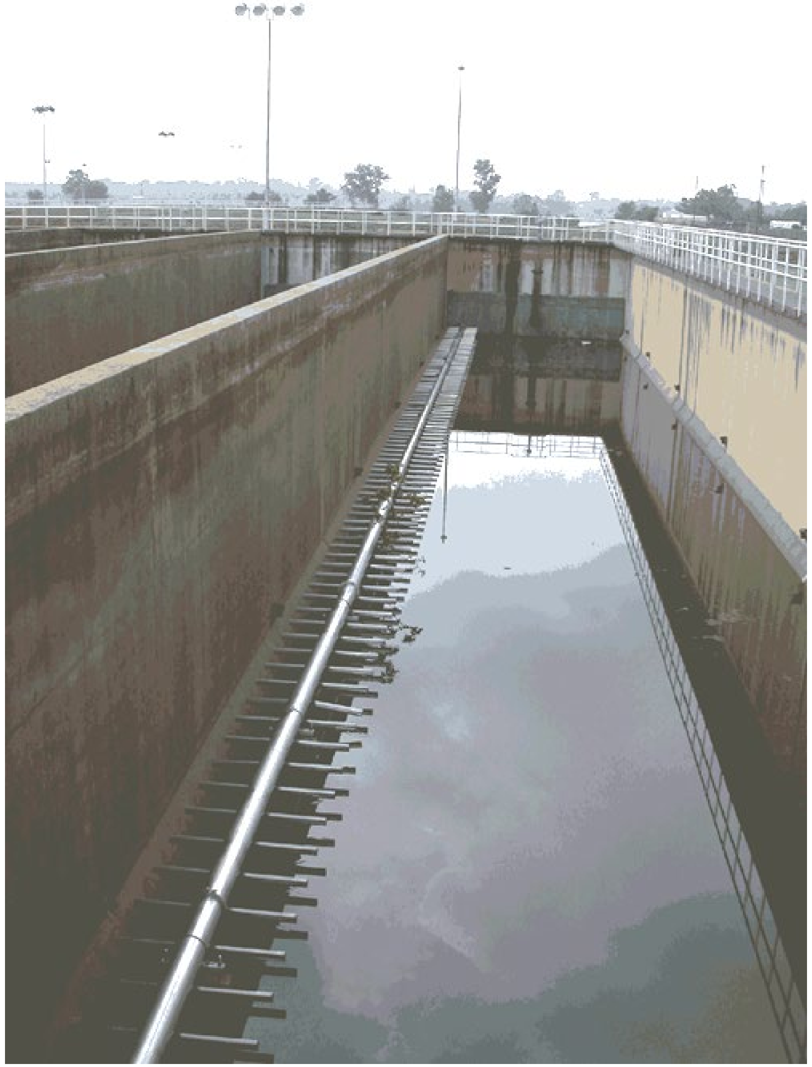
Typical Nonporous Diffuser



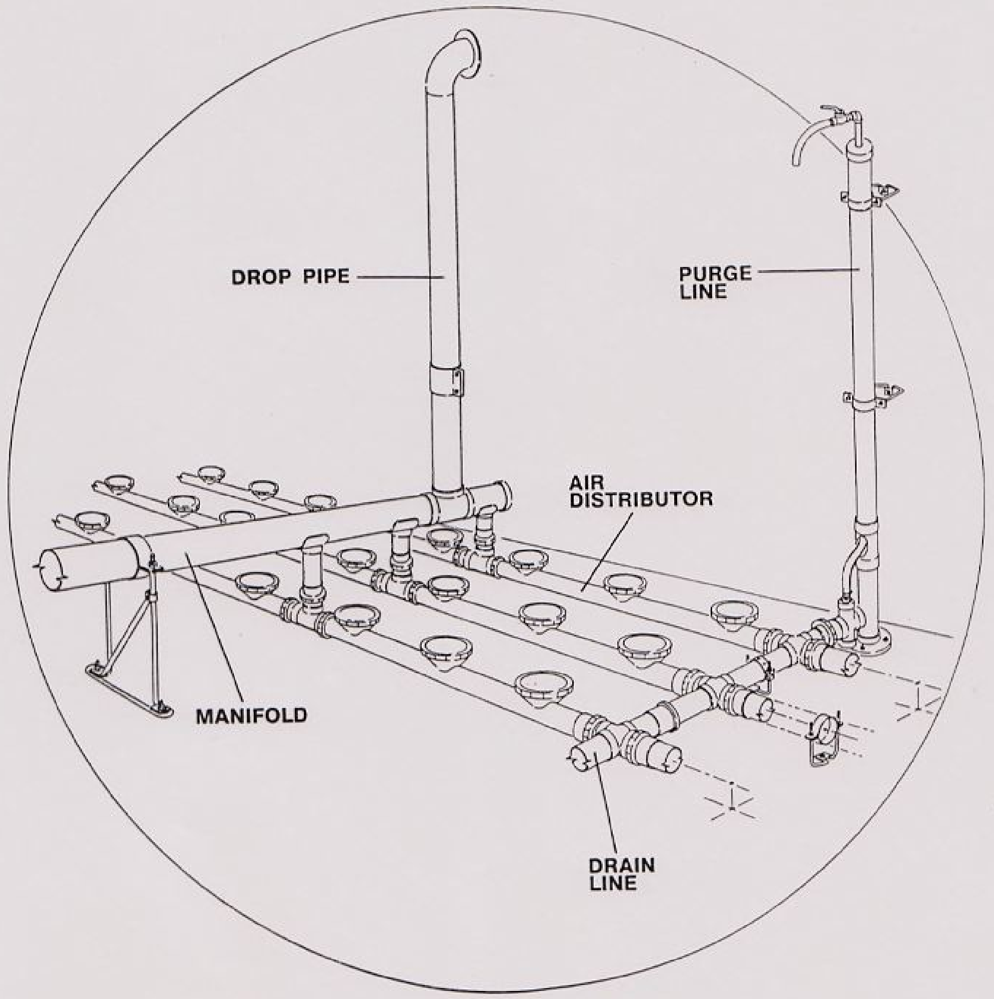
Another Nonporous Diffuser



Nonporous Diffuser Arrangement in a Reactor



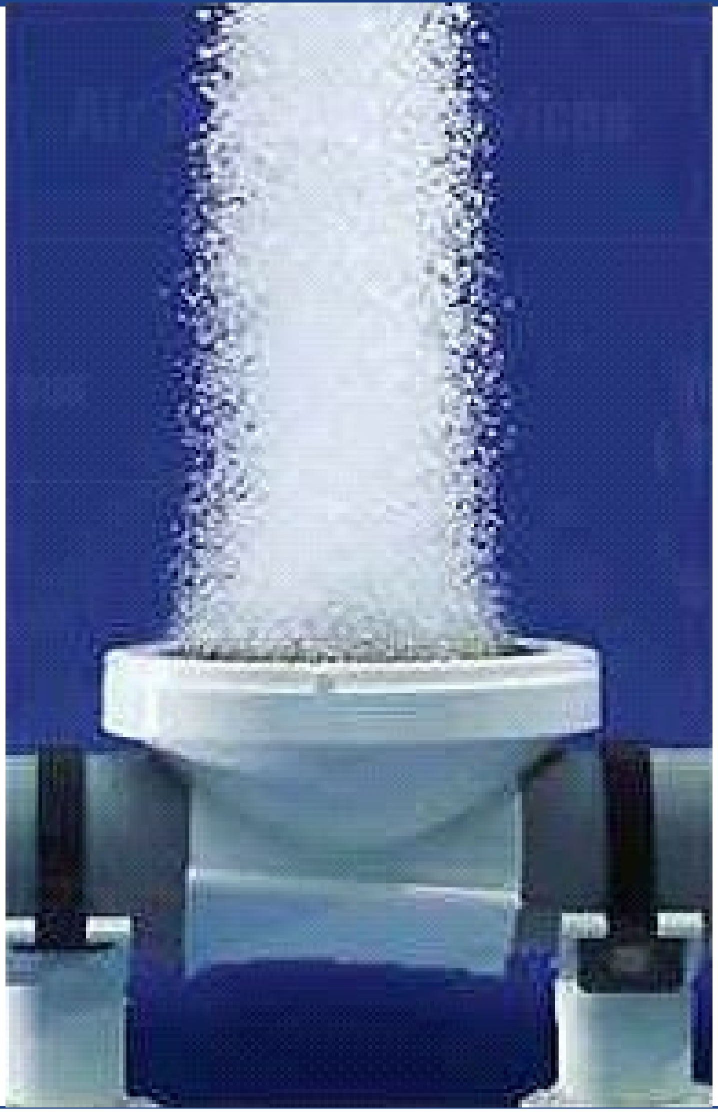
Ceramic Disk Porous Diffusers



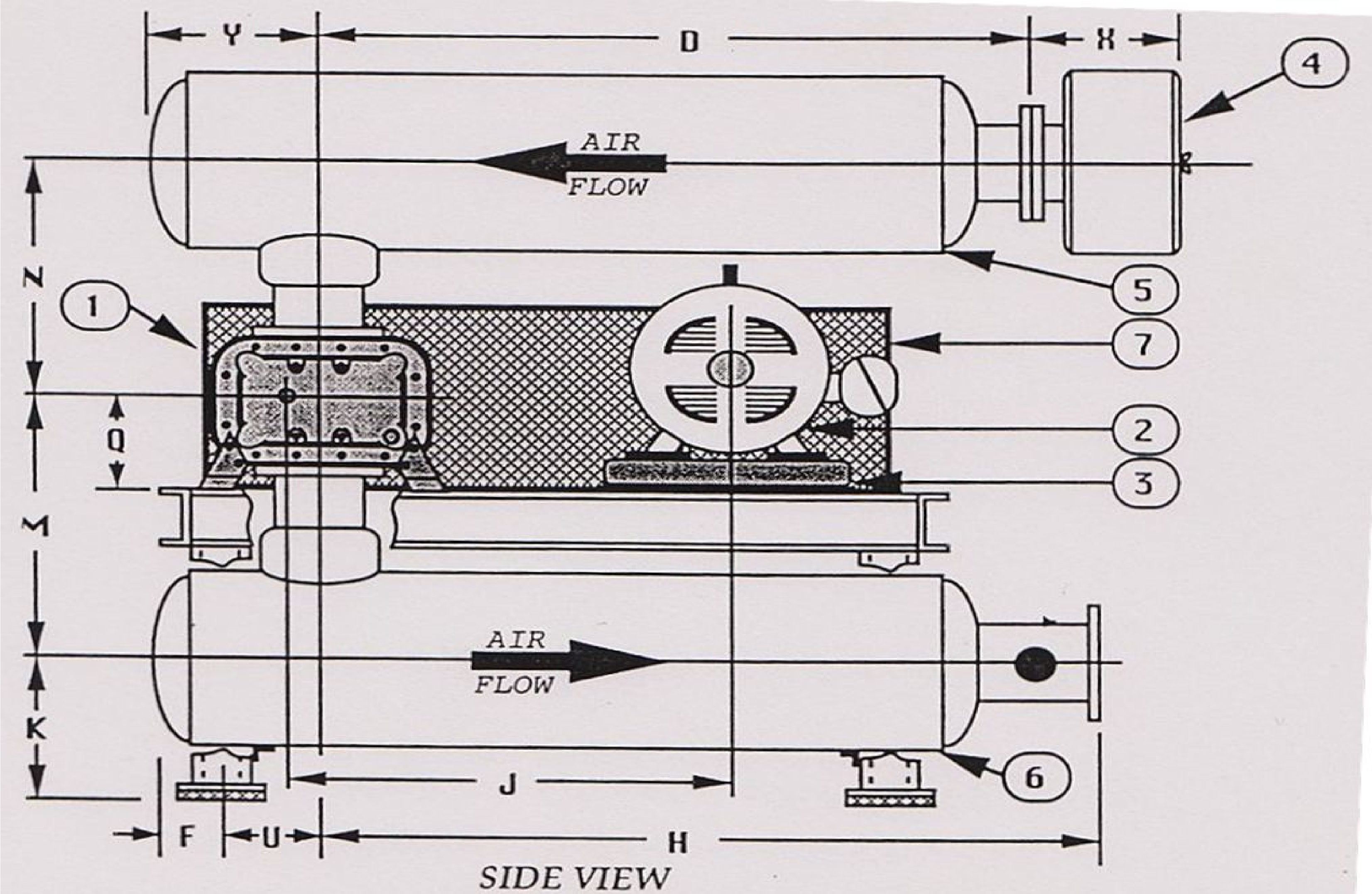
Typical Ceramic Disc Grid Layout

Types of Porous Diffusers

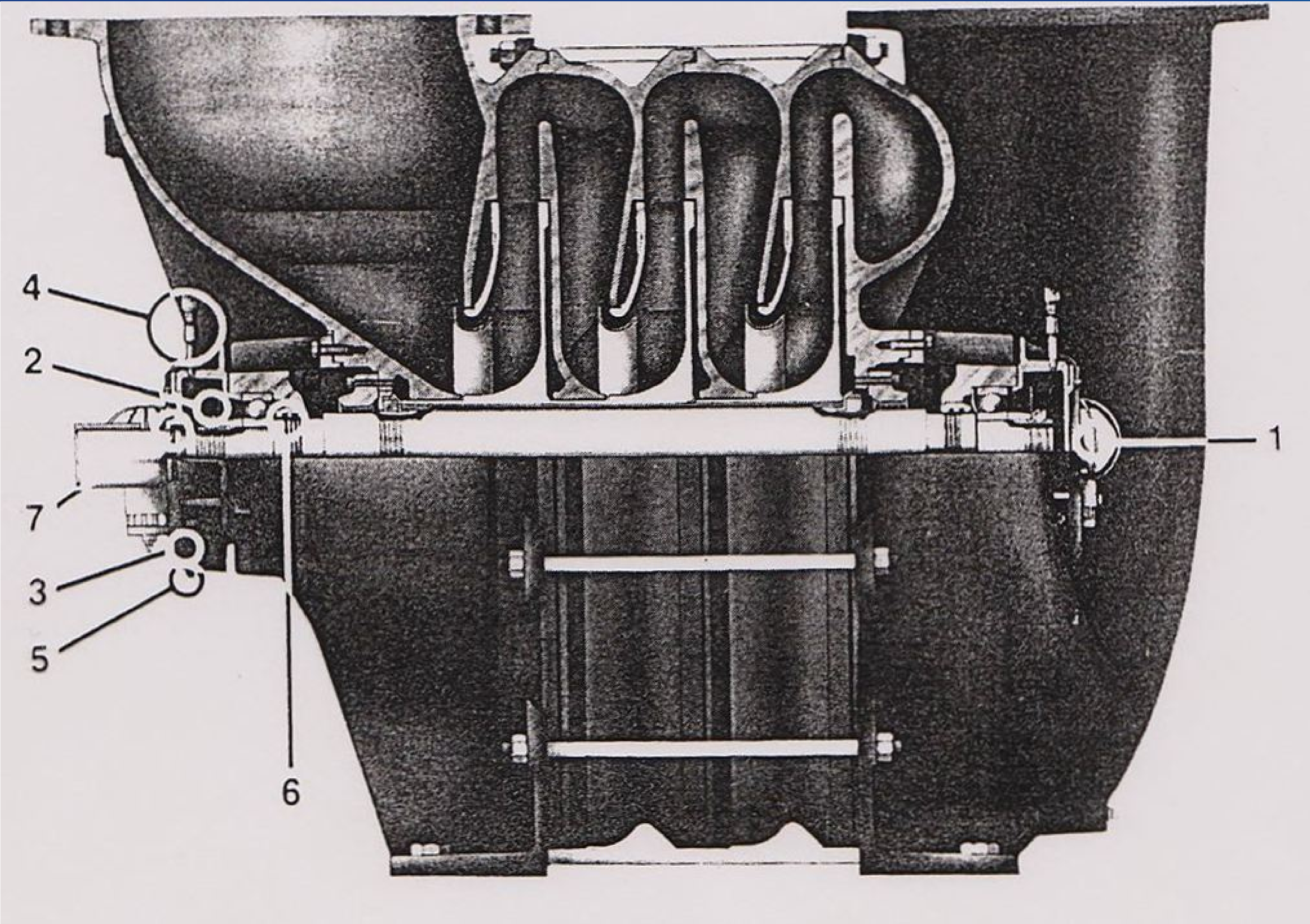
Porous Membrane Diffuser



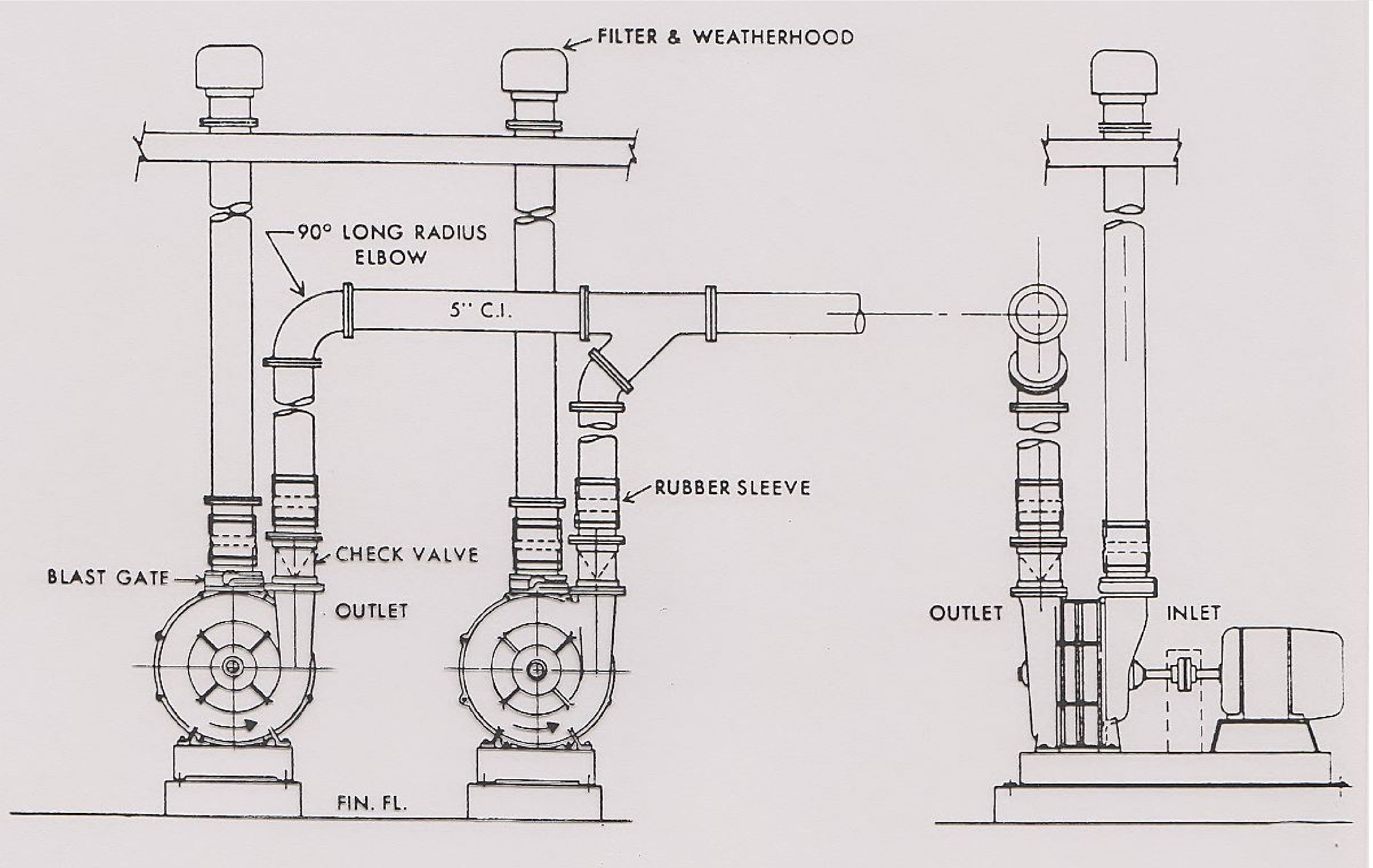
Positive Displacement Blower



Multistage Centrifugal Blower



Single Stage Centrifugal Blowers



Measuring Performance of Diffused Aeration

- Standard oxygen transfer efficiency (SOTE) – oxygen transfer efficiency (%) for standard conditions (tap water, 20^{o}C, initial DO = 0.0 mg/L, sea level)
- Field oxygen transfer efficiency (OTE_f) – mass of oxygen transferred to the liquid from the mass of oxygen supplied (%) at field conditions

Factors Affecting Aerator Performance

- Alpha – ratio of oxygen transfer coefficient in wastewater versus tap water
- Beta – ratio of oxygen saturation concentration in wastewater versus tap water
- Mixed liquor DO concentration – one of the most significant and controllable factors affecting aeration energy efficiency
- Mixed liquor temperature (minor effect if operating DO concentration is 1 to 2 mg/L)
- Site elevation

Control of the Aeration Process

- DO concentration needed for stable biological activity usually is 1.0 to 2.0 mg/L for activated sludge and as low as 1.0 mg/L for nitrification.
- Operating at higher DO concentrations lowers the OTE and increases the energy expended to drive oxygen into solution.

Energy Conservation Measures (ECMs) for Diffused Aeration Systems

- Proper sizing of blowers
- Dedicated blowers for channel aeration
- Configuration of diffusers in a basin
- Intermittent aeration

Proper Sizing of Blowers

- Typically, blower systems should be designed for a minimum 5:1 turndown ratio.
- One design approach:

  design for 4 blowers at 33% each of design loading
- Another design approach:

  design 2 blowers at 25% each of design loading plus 2 blowers at 50% each of design loading

Energy Savings with Blowers

- Replace larger blowers with one or more smaller units
- Install variable frequency drives (VFDs) … may not be a good idea for centrifugal blowers
- Possibly use inlet throttling
- Install DO control system that maintains a setpoint DO concentration (DO control mode only)
- Install DO control system that maintains a preset DO concentration while also keeping the blower near its optimum operating point (DO control & blower discharge pressure control mode)

Example: Replace Existing Blowers with Smaller Units

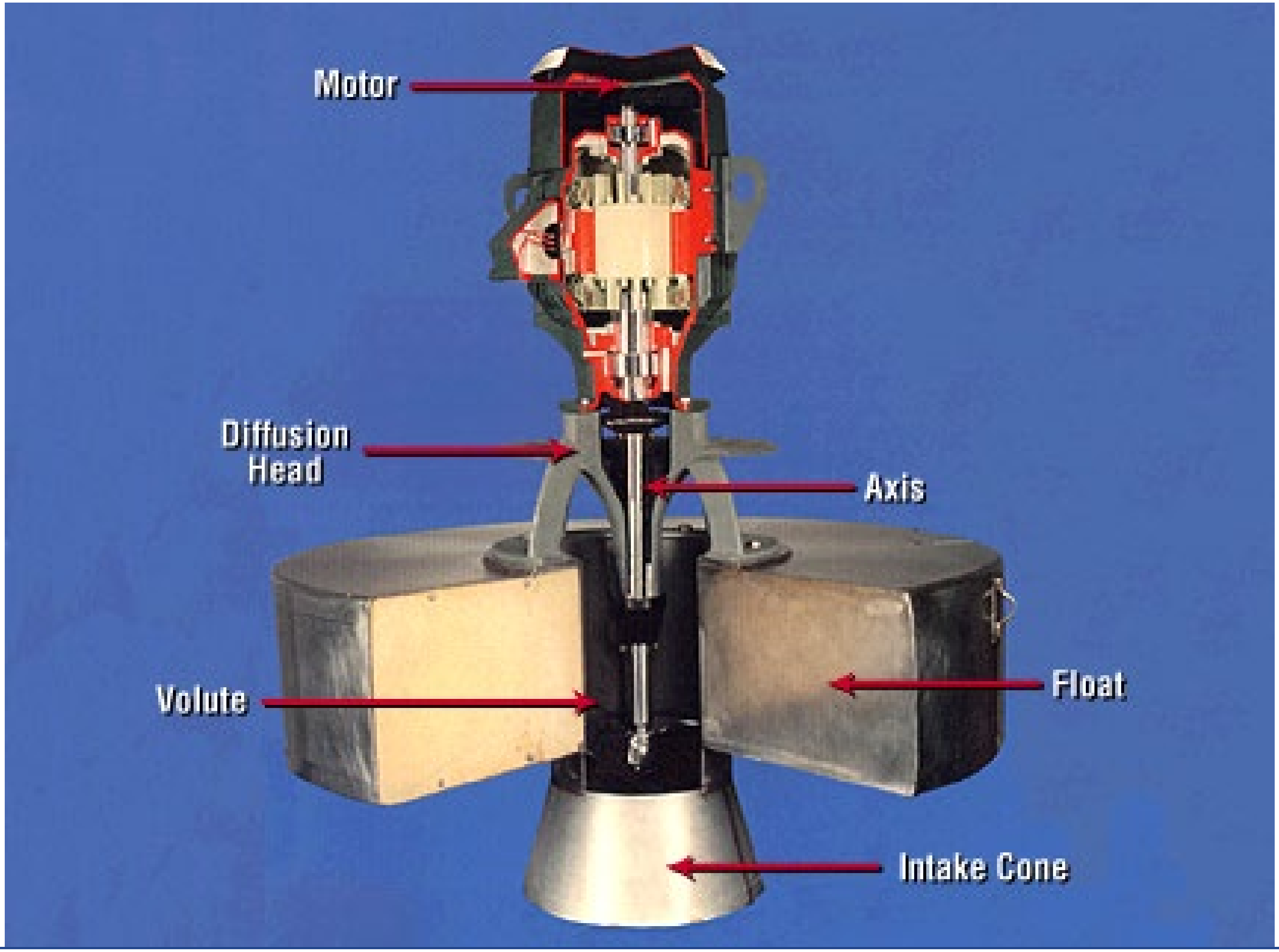
- Design Q = 18.5 mgd
- Actual Q = 10 to 12 mgd
- WWTP had five 700 hp blowers
- With one blower running, DO = 4.5 to 8.0
- They replaced two 700 hp blowers with two 350 hp blowers (they also upgraded DO control system and took 3 of 6 basins out)
- Total energy savings = 1,000,000 kWh per year
- Total costs = $200,000; payback = 3 years

Types of Mechanical (Surface) Aerators

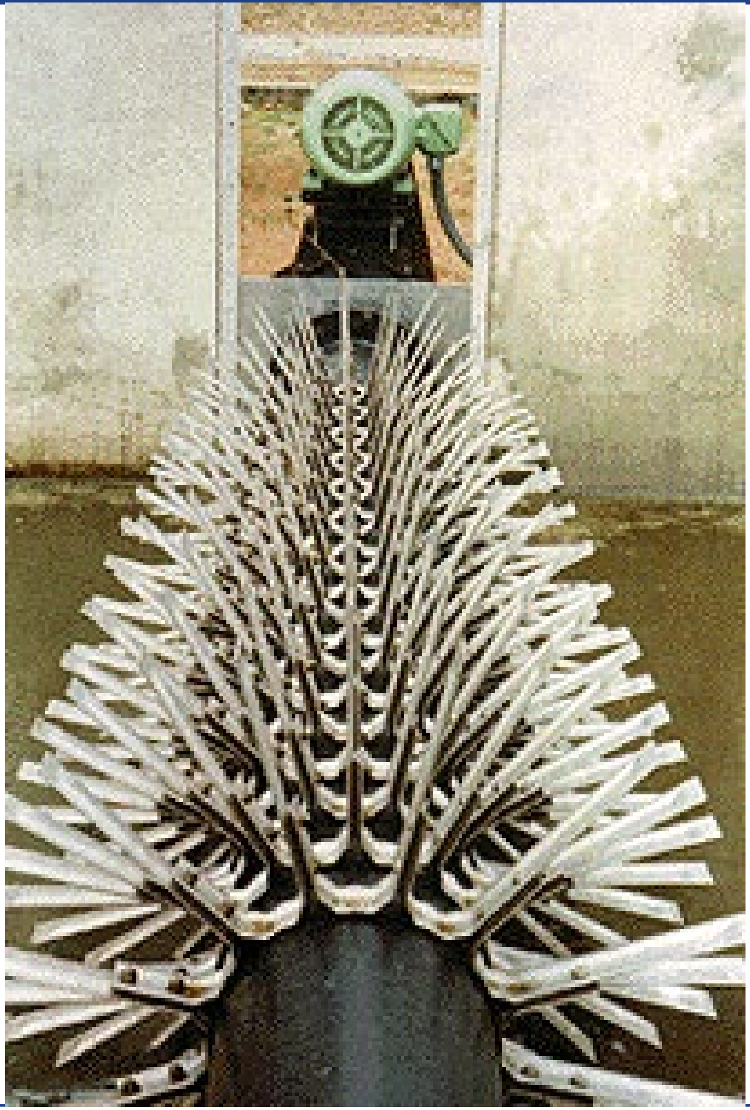
- Common types:
  - Low-speed mechanical aerators
  - Direct drive (high-speed) surface aerators
  - Horizontal rotor surface aerators
  - Aspirating aerators
  - Orbal disk aerators

Slow Speed Vertical Equipment at an Activated Sludge Facility

Axial Flow (high speed) Surface Aerators

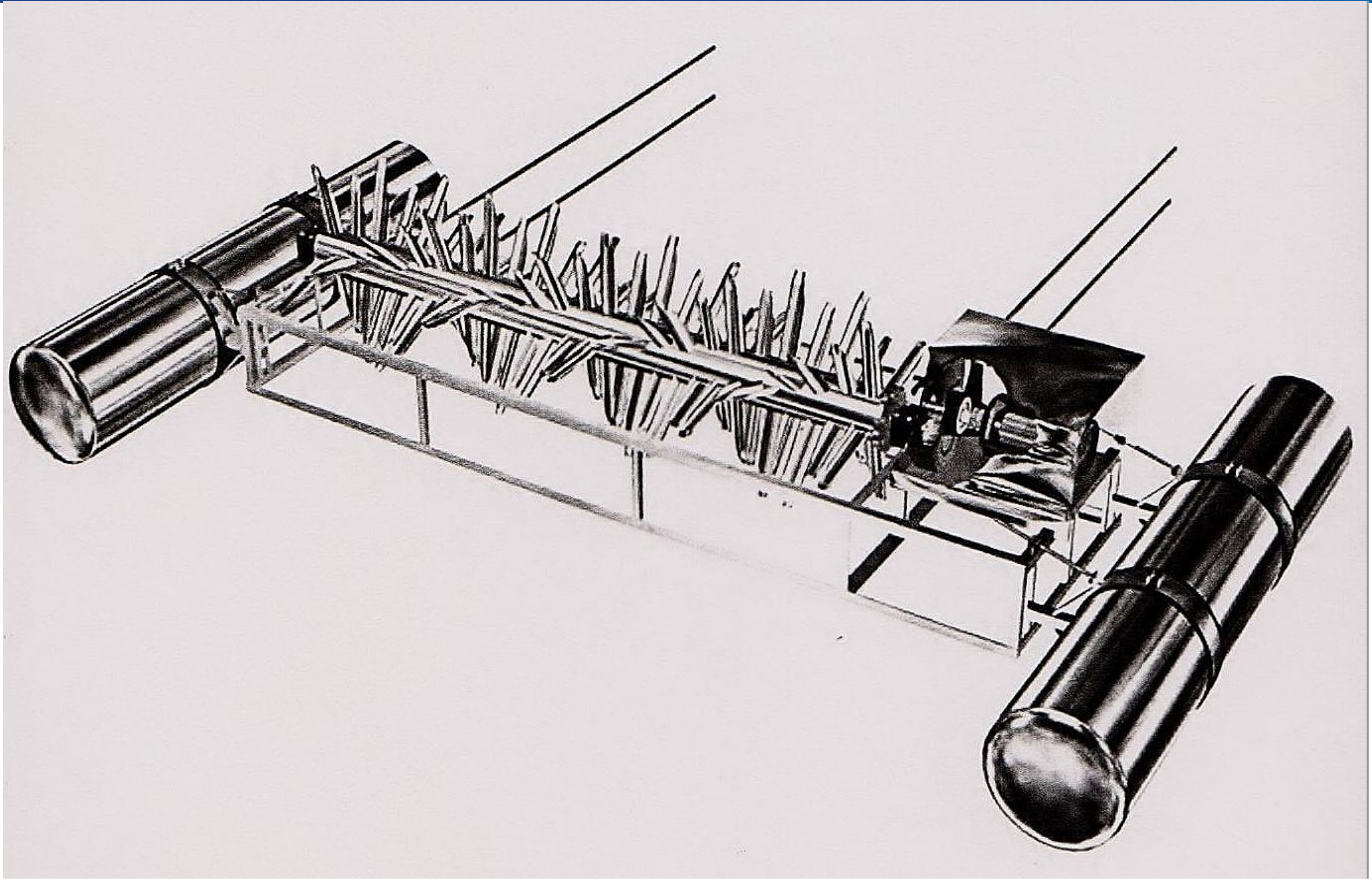


Fixed Horizontal Surface Aerator



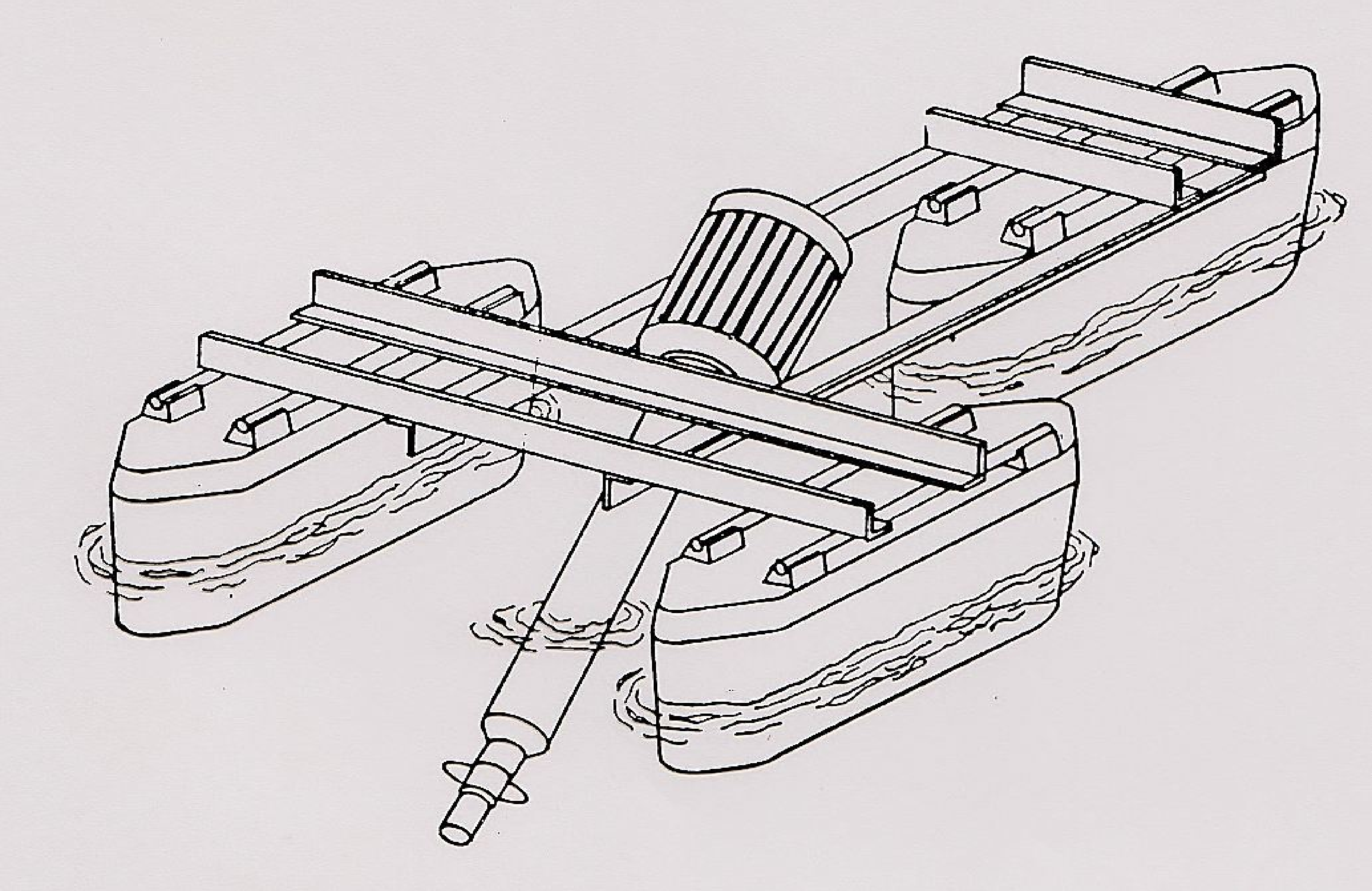
Floating Horizontal Rotor Aerators

Floating Horizontal Rotor Aerator

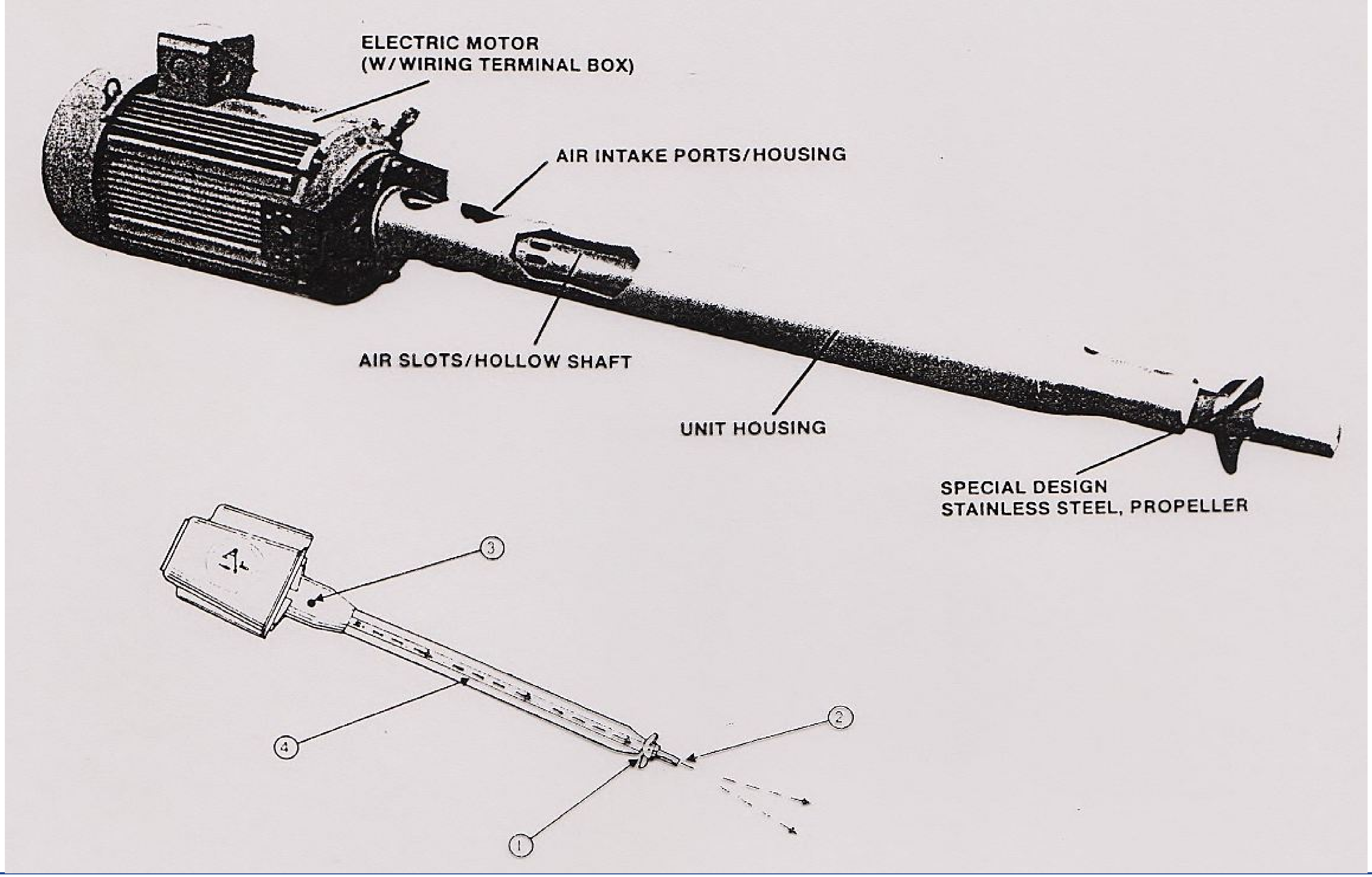


Circular Disk Aerator (Orbal Process)

Aspirating Aerator



Aspirating Aerator



Measuring Performance of Surface Aeration

- **Standard oxygen transfer rate (SOTR)** – oxygen transfer rate for standard conditions (tap water, 20^{o}C, initial DO = 0.0 mg/L, sea level) … usually expressed in lb/(hp-hr)
- **Field oxygen transfer rate (OTR)** – mass of oxygen transferred to the mixed liquor (lb/(hp-hr)) at field conditions

Factors Affecting Aerator Performance

- **Alpha** – ratio of oxygen transfer coefficient in wastewater versus tap water
- **Beta** – ratio of oxygen saturation concentration in wastewater versus tap water
- **Mixed liquor DO concentration** – one of the most significant and controllable factors affecting aeration energy efficiency
- **Mixed liquor temperature** - minor effect if operating DO concentration is 1 to 2 mg/L
- **Site elevation**

$OTR = OTR_{std}\ \alpha\ [(\beta\rho C_s - C)/9.2]\ 1.024^{(T-20)}$

OTR (lb O_2 hp^{-1} hour^{-1}) = oxygen transfer rate at field conditions

OTR_{std} (lb O_2 hp^{-1} hour^{-1}) = oxygen transfer rate at 20°C, 1 atm, tap water, and initial DO = zero mg/L

C = dissolved oxygen level in basin (typically 1 to 2 mg/L)

C_s = saturated dissolved oxygen level in mg/L

α = (K_La of wastewater)/(K_La of tap water) Use α = 0.80 to 0.90 unless specified otherwise.

β = C_s wastewater/C_s tap water = 0.92 for municipal wastewater

ρ = factor that corrects for elevation differences

Example of Using Previous Equation

- OTR_{std} = 3.0 lb/hp-hr
- $\alpha = 0.84$, $\beta = 0.92$, $\rho = 1$
- T = 10°C → C_s = 11.33 mg/L
- C = 2.0 mg/L
- Elevation < 500 feet

OTR = 1.80 lb/hp-hr

Example: Changing Operating Temperature

- OTR_{std} = 3.0 lb/hp-hr
- α = 0.84, β = 0.92, ρ = 1
- T = 30°C → C_s = 7.63 mg/L
- C = 2.0 mg/L
- Elevation < 500 feet

OTR = 1.71 lb/hp-hr

Example: Changing Operating DO Concentration

- OTR_{std} = 3.0 lb/hp-hr
- $\alpha = 0.84$, $\beta = 0.92$, $\rho = 1$
- $T = 30^{o}C \rightarrow C_s = 7.63$ mg/L
- $C = 4.0$ mg/L
- Elevation < 500 feet

OTR = 1.01 lb/hp-hr

Other Potential Problems with Excess DO

- Poor sludge settling (over-oxidized floc)
- Increased foam
- Negative impacts on the anoxic zone of a biological nitrogen removal system due to high DO levels in the recycle flow

Approximate Field O_2 Transfer Rates

- *Pump type aerators*

  1.4 to 2.3 lb O_2/(hp-hr)
- *Horizontal rotor aerators*

  1.4 to 1.8 lb O_2/(hp-hr)
- *Orbal disk aerators*

  1.3 to 1.5 lb O_2/(hp-hr)
- *Aspirating aerators*

  1.0 to 1.3 lb O_2/(hp-hr)

α = 0.84, β = 0.92, ρ = 1, DO = 2 mg/L, Elevation < 500 ft

Approximate Field O_2 Transfer Rates

- *Nonporous diffusers*

  1.0 to 1.5 lb O_2/(hp-hr)

- *Porous diffusers*

  1.5 to 2.3 lb O_2/(hp-hr)

α = 0.84, β = 0.92, ρ = 1, DO = 2 mg/L

Elevation < 500 ft; compressor efficiency = 75%

Tank depth = 15 ft; diffusers located 1.5 ft above tank bottom

ECMs for Surface Aerators

- Adjust submergence of fixed mechanical aerators by using adjustable weirs
- Low-speed mechanical aerators provide higher oxygen transfer rates than high-speed machines
- Cycle aerators off a few hours each day to promote denitrification and to save energy
- Use mechanical aerators with multiple impellers
- Operate in the lowest acceptable DO concentration range

Intermittent Aeration

- Reduce the number of hours an aeration system operates
- Not appropriate for all facilities
- Control cycle length with DO concentration (automatic control) or on a strictly time basis
- When controlling with DO concentration, air flow is turned off at a set high level and turned back on at a set lower limit
- Consider solids settling within the basin

Automated DO Control

- A WWTP may save considerable energy by quickly adjusting to variable conditions within the basin
- Oxygen required for biotreatment is proportional to organic and ammonia loading in the influent wastewater.
- Oxygen demand for aeration dips in the middle of the night and peaks in the morning and evening.

Automated DO Control

- Tight DO control can save a WWTP between **10% and 30% of total energy costs.**
- Energy savings will be site specific and are highly dependent on the control system in place prior to the upgrade to automated process control.
- The payback period for installing automated DO control is typically a few years.

Thank you!

For Questions or Comments please reach out to the following:

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