Aeration

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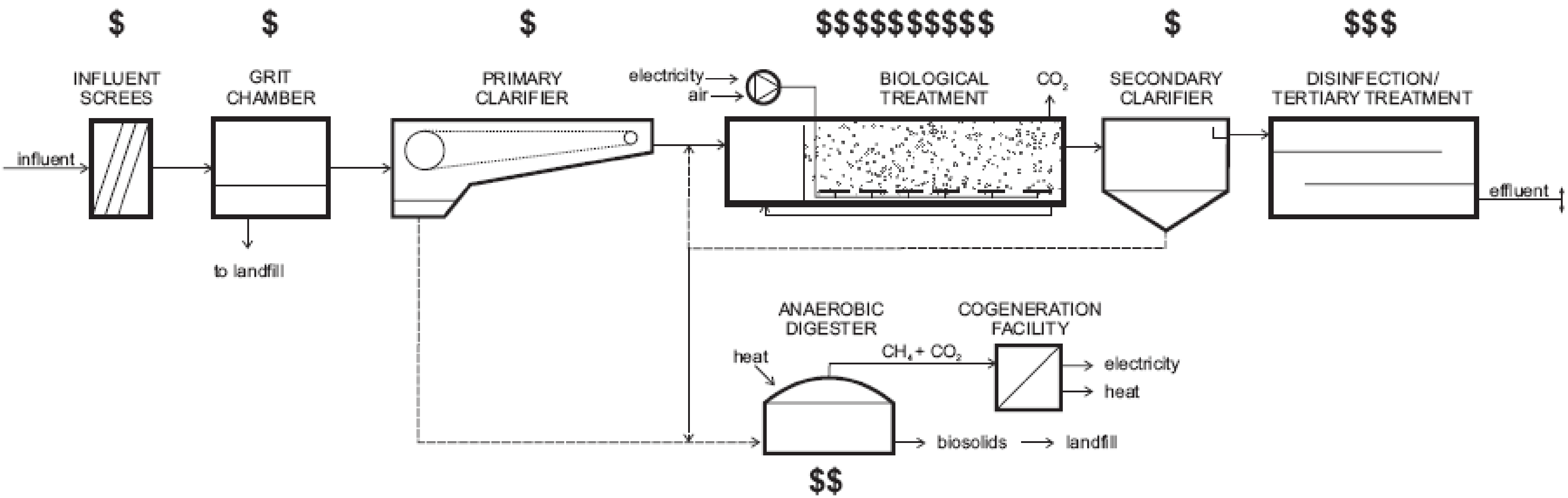
Goals

- Our first goal is to learn sufficient theory to understand aeration processes.
- The second goal is to understand the practical aspects of various aeration devices in order to select aeration systems that can provide the required transfer and be maintainable for different levels of operational expertise
- Other issues that impact aeration system selection are stripping of organic compounds (odors), production of mist and fog, and cooling.
- The overall goal is to provide maintainable aeration systems at the least energy cost that meets the owner’s expectation for maintenance, odor production, misting and fog and cooling.

Fig 1. Plant Overview



Aeration occurs in many water and wastewater treatment processes, but in the activated sludge process and its variants, it consumes more energy than other processes, by far. Reducing energy consumption during aeration is usually the best initial step to minimize energy cost.

Nomenclature

- Both the US and the EU have standards to measure oxygen transfer in clean water
- Clean water results are most often used for design and specifying treatment plants
- The standards define nomenclature which should always be used
- Because aeration systems are expensive, their selection can become litigious. Using standard methods and nomenclature can avoid legal cost and delays
- Nomenclature has been listed in a separate handout, but the major terms are listed on the next slides.

Nomenclature 2

Parameter	Definition	Remarks
OTR	Oxygen transfer rate in clean water	$= k_L a\ (DO - DO_{sat})\ V$
SOTR	Oxygen transfer rate in standard conditions in clean water	
OTE	Oxygen transfer efficiency in clean water	$= (O_{2,\ in} - O_{2,\ out}) / O_{2,\ in}$
SOTE	Oxygen transfer efficiency in standard conditions in clean water	
AE	Aeration efficiency in clean water	= OTR / P
SAE	Aeration efficiency in standard conditions in clean water	
$k_L a$	Liquid-side mass transfer coefficient	Measured in clean water tests

Standard conditions are defined as 20°C, 1 atm, zero salinity, zero DO in water.

Key: P = power drawn; V = water volume.

Nomenclature 3

α Alpha factor, i.e. ratio of process- to clean- water mass transfer.
= αSOTE / SOTE , or

= kLa process water / k_La clean water

F Fouling factor = αSOTEnew diffuser / αSOTEused diffuser

αF Alpha factor for used diffusers = α F

αSOTE Oxygen transfer efficiency in standard conditions in process water

αFSOTE Oxygen transfer efficiency in standard conditions in process water for used diffusers

αSAE Aeration efficiency in standard conditions in process water

αFSAE Aeration efficiency in standard conditions in process water for used diffusers

Theory

- Oxygen transfer, and transfer of other sparingly soluble gases can be modeled using the two film theory or *two resistance theory.*
- The two film theory dates back to Lewis and Whitman’s paper in 1924.
- The two film theory has been extended by Higbie (1935) and Dankwertz(1951) but these extensions generally are not needed when designing aeration systems for wastewater treatment.
- The extensions become important when considering stripping of volatile organic compounds (VOCs)

Two Film Theory

$$OTR = k_L a \cdot (DO_{sat} - DO) \cdot V$$

where	$k_L a$	=	liquid-side mass transfer coefficient (h^{-1})
	DO	=	dissolved oxygen in water (kgO2 m^{-3})
	DO_{sat}	=	dissolved oxygen in water at saturation (kgO2 m^{-3})
	V	=	water volume (m^3).

Two Film Theory 2

- The OTR is the actual mass of oxygen transferred per unit time and it is the key process variable for design
- The DO saturation concentration is the concentration of dissolved oxygen at saturation with no reactions in the liquid, and includes the impact of hydrostatic pressure. Subsurface aeration systems, which release bubbles below the surface, always have higher saturation concentrations than the “text book” values of DO_{sat} due to this hydrostatic pressure.
- The mass transfer coefficient, $k_L a$ is a function of the aeration system and the tank geometry.

Power Input

- The mass of oxygen transferred per unit of power input is the most important efficiency parameter. It defines the amount of energy required to treat the wastewater, which as noted earlier is usually 60% or more of the total energy cost, and is expressed as an aeration efficiency, equal to the OTR divided by the power input, as follows.

$$AE = \frac{OTR}{P}$$

Oxygen Transfer Efficiency

- There are different types of aeration systems, but subsurface or diffused aeration systems are most common, especially for large plants in urban areas
- For these types of aeration systems, it is common to define the oxygen transfer efficiency, expressed as a percent, as follows:

$$OTE = \frac{(O_{2,in} - O_{2,out})}{O_{2,in}}$$

Where $O_{2,in}$ and $O_{2,out}$ are mass flow rates

Standard Conditions

- In order for manufacturers to provide equipment without bias for site specific conditions, it is common to report the various transfer parameters at standard conditions. Standard conditions include tap water, 20^{o}C, 1 atm pressure, zero salinity, etc. There we can define standard parameters, as follows:

Standard Oxygen Transfer Efficiency (SOTE, %)

Standard Oxygen Transfer Rate (SOTR, $kg_{O2}\ h^{-1}$)

Standard Aeration Efficiency (SAE, $kg_{O2}\ kW^{-1}\ h^{-1}$).

Process Conditions

- Translating or correcting standard parameters to non-standard or process conditions is the key job of the consultant. Manufacturers of aeration systems can advise, but cannot be held accountable for this key engineering task
- Most often, three empirical parameters are used for this translation, called the α (alpha) factor, β (beta) factor and θ (theta) factor.
- The α factor accounts for contaminants in the wastewater, and soaps, detergents have the most impact on the α factor. The α factor is the most uncertain of the various oxygen transfer parameters and is the most difficult to accurately know.

Process Conditions 2

$$OTR = \alpha k_L a \cdot (\beta DO_{sat} - DO) \cdot V$$

where α = alpha factor, or the reduction in transfer rate caused by impurities in the wastewater

β = beta factor, or the reduction in transfer rate caused by the increased salinity of the wastewater

Process Conditions 3

- The α factor is expressed as the ratio of process to clean water conditions, as follows:

$$\alpha = \frac{\left(k_L a\right)_{\text{process water}}}{\left(k_L a\right)_{\text{clean water}}}$$

Conversion from Clean to Process Water Transfer Rates

$$\mathrm{OTR} = \mathrm{SOTR}\ \frac{\alpha(\beta C^{*}_{\infty T} - DO)}{C^{*}_{\infty 20}}\,\theta^{T-20}$$

Where θ = 1.024

DO = operating DO concentration (~ 2 mg/L)

α = alpha factor. For fouled diffusers, we typically use additional derating, or F factor.

Process Conditions 4

- The α factor can also be expressed as the ratio of oxygen transfer efficiencies, after other conditions have been corrected, as follows:

$$\alpha = \frac{\alpha \mathrm{SOTE}}{\mathrm{SOTE}}$$

- The αSOTE is the most useful parameter for comparing aeration systems, since it excludes the effects of all conditions except for water impurities

Process Conditions 4

- The αSOTE is the most useful parameter for comparing aeration systems, since it excludes the effects of all conditions except for water impurities
- It can be specified for a specific water depth or on a per depth basis.
- For example, fine pore, full floor coverage aeration systems may have a clean water efficiency of 6 to 7.5% SOTE/m and 3 to 4% αSOTE/m of diffuser submergence

Power Measurement

- Since aeration systems are competitively bid on the basis of oxygen transfer per unit of power consumed, power measurement becomes very important
- There are three types of power measurements:
  - Wire power – this is the power that is actually used by the aeration system, and includes all inefficiencies of the system, such as motor and blower inefficiencies
  - Brake power – this can be specified as the output power of a motor or gear box. It can be calculated as the torque times the RPM
  - Water power – this is the power that is actually transferred to the fluid being aerated. For a surface aerator, water power excludes the motor, coupling and gear box inefficiencies.
- It is essential to be clear on power definitions when designing and specifying aeration systems.

Power Measurement and Efficiency

- The differences in actual power values using the different methods can be substantial.
- Wire power differs from brake power, when defined as motor output power, by the motor efficiencies. Modern motors in the 100 kW range have efficiencies of approximately 95%
- Small motors and old technology motors can have efficiencies less than 80%.
- It is often economically viable to replace old motors with modern, high efficiency or “premium” motors based on power savings alone.

Gear Box Efficiency

- New, large (100 kW) gearboxes may have efficiencies of 90% to 93%. Efficiency declines with age.
- The number of stages of RPM reduction impact efficiency. Most aerator gear boxes have two or three stages
- Small gearboxes have much lower efficiencies and combined motor-gearbox efficiency for 20 kW devices may be 80%
- Efficiencies are specific to the manufacturer and require diligence on the part of the designer to correctly analyze.

Blower Efficiency

- Several types of blowers can be used for subsurface aeration.
- Positive displacement (PD) blowers are best suited for small plants and have efficiencies of 70 to 75% . Efficiency declines with age. Poorly maintained PD blowers can be very inefficient and are good candidates for replacement based on energy savings
- Centrifugal blowers are most often used for larger plants, hence there is incentive to make them more efficient .
- Centrifugal blowers with inlet guide vanes and outlet diffusers are the most efficient with efficiencies approaching 80%. Additionally, two sets of controls, vanes and diffusers, allows the blower to be more efficient over a greater range of flow rates – more “turn up” and “turn down” ability.

Aeration System Types

- There are generally three types of aeration systems:
  - Surface aerators, which use a motor at the surface to power a propeller or brush that splashes liquid into the air and induces fluid movement in the tank for mixing
  - Diffused aerators, which use porous devices below the surface. Compressed air is released through the pores or orifices or holes
  - Devices that combine both mechanisms, such as turbines which have a propeller below the surface that shears large bubbles being supplied by a blower into smaller bubbles.
- There are other types of aeration systems, such as membranes that work from molecular diffusion, but they are far less popular and not covered in this text.

Aeration System Types 2

- Surface aerators can be further classified into high speed, low speed, with horizontal or vertical shafts.
- High speed surface aerators use motors without gear boxes and a propeller that looks like a boat propeller. They are usually smaller than 50kW and operate at 900 to 1200 RPM
- Low speed aerators always use a gear box, can be as large as 150kW and operate at 40 to 60 RPM

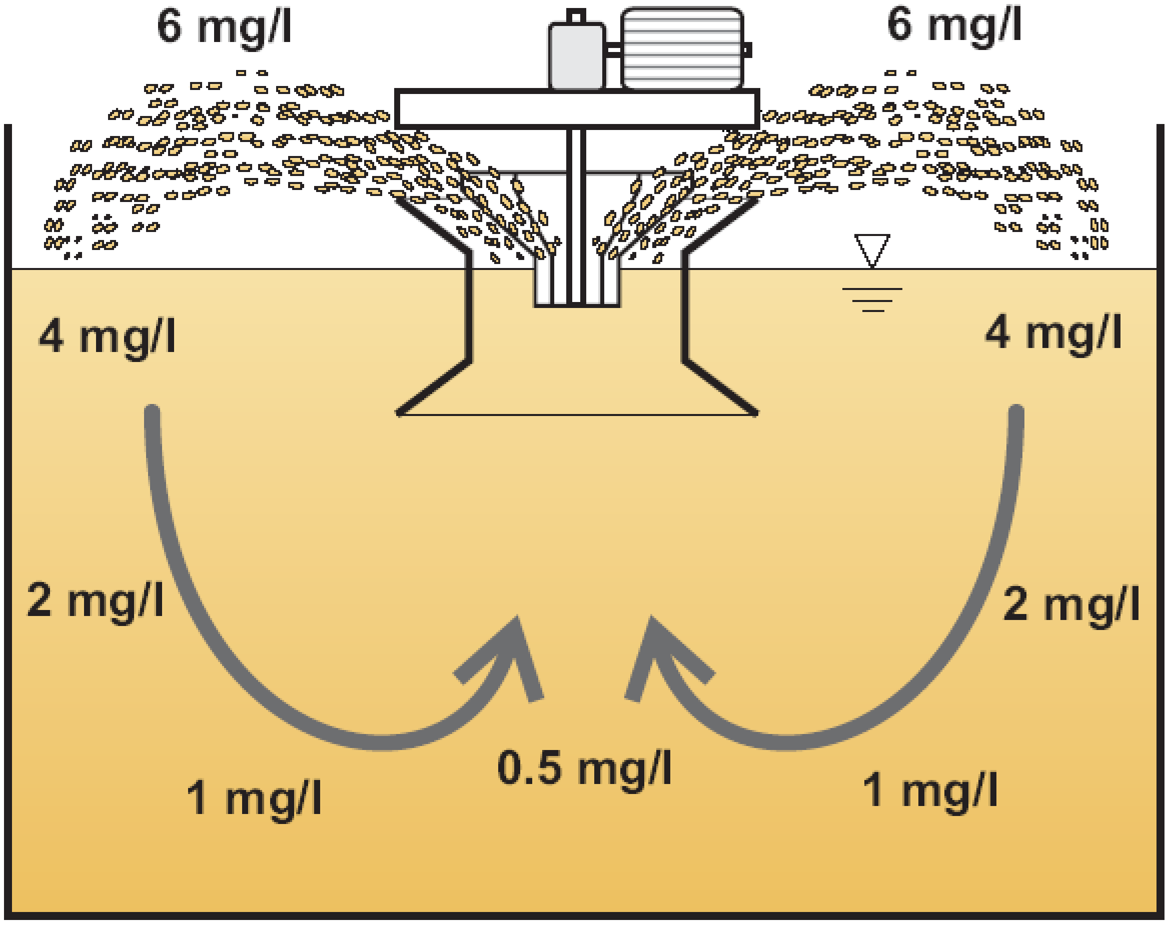
Aeration System Types 3

- Diffused aeration systems are classified as coarse bubble of fine pore.
- Fine pore diffusers produce 1 to 3 mm bubbles by passing gas through a punched membrane or porous stone. They are called fine pore to distinguish them from turbine aerators which create fine bubbles using mechanical shearing action
- Diffused aerators are also classified by geometry, such as “full floor coverage” or “spiral roll.” Full floor coverage systems spread the air across the entire tank bottom, while spiral roll systems may have diffusers in narrow bands, often at the tank wall, and induce a rolling action of the fluid.

Surface Aerators

- Surface aerators belong to first generation of oxygen transfer technologies. They are typically characterised by high OTR and low SAE values (in the range of 0.9-2.1 $kgO_2\ kWh^{-1}$). Surface aerators shear the liquid into small droplets which are spread in a turbulent plume at several metres per second. The travelling droplets are in turbulent contact with the atmospheric air and typically oxygenate to at least half-saturation. As soon as they land onto the liquid free surface they mix with the liquid bulk, producing a typical DO pattern as in Fig. 2. There is no way to measure the mass of oxygen absorbed from the air around the aerator, therefore the SOTE or OTE cannot be defined. Efficiencies can only be quantified as SAE or AE.

Fig. 2 Low Speed, Vertical Shaft Surface Aerator



Surface Aerator DO Pattern

- Surface aerators always “pump in a circle”
- This means that there is always a DO gradient in the tank
- For completely aerobic conditions, the fluid returning to the aerator must have positive DO and it must be sufficiently high to keep the floc centers aerobic
- In nitrifying systems, especially fully loaded or overloaded systems, it is common to observe simultaneous nitrification-denitrification, because the circulating fluid becomes anoxic at some point in the circulation pattern.

Surface Aerator Applications

- High speed surface aerators find their greatest application in lagoons or oxidation ponds. Often an overloaded lagoon is upgraded by adding surface aerators.
- Lagoon water depth is restricted when using surface aerators. The impeller must be at least one meter above the bottom and sometimes more depending on the lagoon materials. Surface aerators in too shallow water will “dig a hole” in the lagoon bottom, destroy liners, kick up rocks and soil causing treatment problems and damage the aerator (see picture)
- At greater depths, high speed surface aerators require draft tubes, which extend the influence of the aerators mixing to lower depths. Surface aerators are rarely used at greater than 4 to 5 m depth, unless they are equipped with lower propellers or draft tubes

Surface Aerator Applications 2

- Low speed aerators are more efficient but require greater support and are most successfully used when mounted on piers on decks.
- More engineering and planning are required to use surface aerators, such as designing the structural supports, baffles and tank walls/bottom. Long delivery time is common
- Remember than a method to transfer the heavy aerator (> 10,000 kg) into and out of the tank or lagoon must be provided – heavy duty piers or crane access.
- Surface aerators with lower propellers can be successfully used in very deep tanks (~10m) and are commonly used with deep tanks in the high purity oxygen activated sludge process (HPO-AS) in the United States.

Pier Mounted, Surface Aerator with Lower Propeller

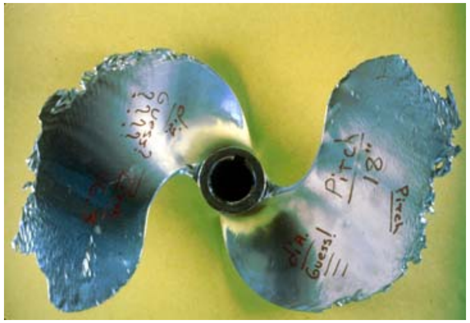
During construction - note that the piers Also serve as anti-vortex baffles

During operation – the spray provides aeration but can causes misting/odor problems

Examples of High Speed Surface Aerators

In a low-rate polishing lagoon

In an activated sludge tank



Propeller damage

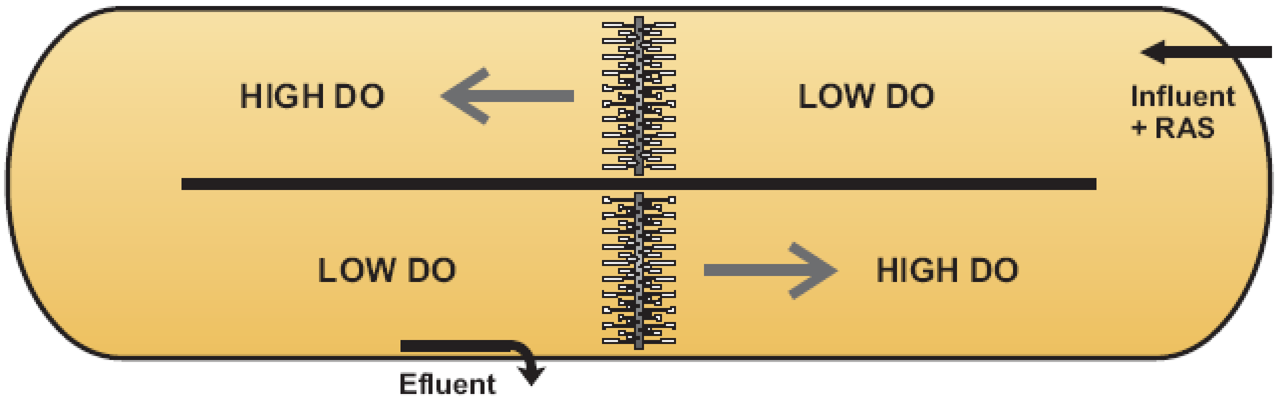
Empirical Design Considerations

- The surface spray or “umbrella” must never strike the tank walls or the cover, if it is a covered tank.
- Reduced efficiency occurs and erosion gradually destroys the tank (even concrete) or lagoon walls
- Manufactures have empirical information on the diameter and height of the umbrella for their equipment
- Similarly manufactures have information on the zone of influence – horizontal and vertical, of the aerator
- Warranties usually include oxygen transfer rates as well as minimum fluid velocities (> 0.3m/sec), uniform TSS profiles, but never uniform DO profiles
- The design engineer’s job is not to determine the empirical design parameters, but to verify them, with independent testing, by witnessing shop testing, or observing operation in existing treatment plants.

Horizontal Shaft Surface Aerators

- Horizontal shaft aerators, called brushes or rotors, find application in oxidation ditches, and sometimes in lagoons
- They provide aeration as well as imparting a circulating velocity in the ditch (> 0.3m/sec at the bottom)
- Power input can be modulated by varying liquid depth or rotor submergence
- There are several manufacturers that provide vertical shaft aerators for ditches, but require special geometry.
- In some existing installations, these aerators are being phased out in favor of mixing pumps with fine pore diffusers

A Ditch Example



Rotor out of the water

Rotor operating, note the dried spray - a source of odors.

A Less Common Lagoon Application

Floating brush aerator provides mixing in a large lagoon

Other Considerations

- Surface aerators provide the greatest evaporation and therefore provide the greatest cooling. This is especially true in dry climates. Wind velocity is an important parameter. Surface aerators may cause a 4^{o}C temperature reduction compared to fine pore aerators for the same conditions. This can be important to maintain nitrification in winter.
- Occasionally surface aerators are chosen simply because of their cooling ability, such as in petroleum refinery wastewater treatment in warm climates, or to avoid heat impacts of effluents on receiving waters
- Power draw is a function of propeller submergence. High water can overload fixed mounted aerators and burn on the motors
- As we shall see, surface aerators have higher alpha factors. They do not have the greatest clean water efficiency, but the higher alpha factors partially compensates.
- Surface aerators can usually be designed so that maintenance can be performed without dewatering the tank or lagoon.

Diffused Aeration

- Diffused aeration, sometimes called subsurface aeration, is divided into two categories:
  - Coarse bubble, with orifices of 5 mm to 12 mm, producing large, non-spherical, rapidly rising bubbles that can be as large as 50 mm in diameter
  - Fine pore, producing mostly spherical bubbles 1 to 3 mm in diameter, through porous plates, discs or domes (ceramic or plastic), or punched plastic or rubber membranes
- In former times, coarse bubble diffusers dominated the municipal field, but now fine pore diffusers are dominant, and they generally save at least half the power of coarse bubble system providing the same SOTR.

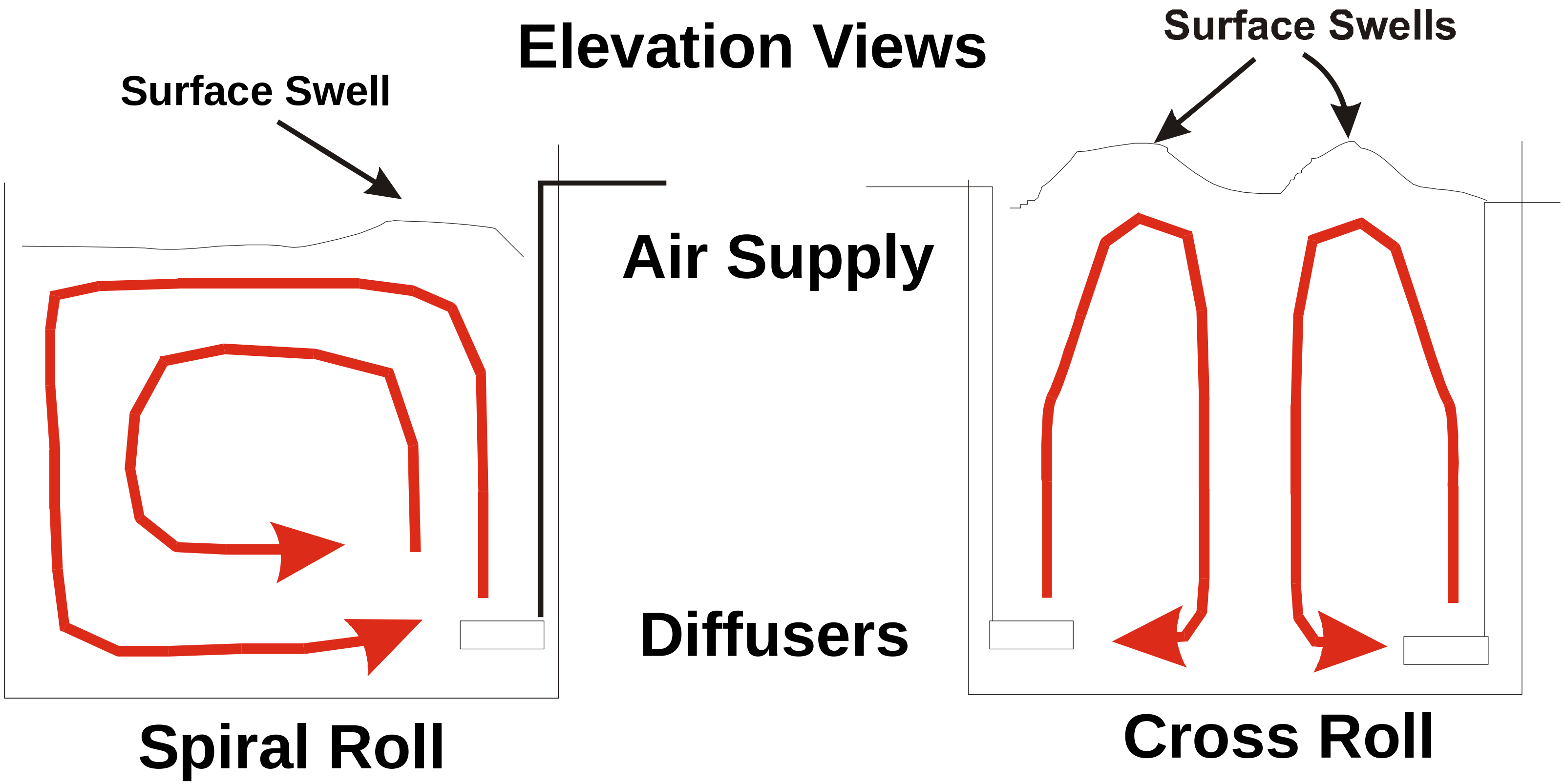
Diffuser Maintenance

- Coarse bubble diffusers need little maintenance and a system might be installed and operated five or more years without maintenance. Problems requiring maintenance are corrosion of piping or diffusers, line breakage, but rarely diffuser plugging, since the orifices are so large.
- Fine pore diffusers always require cleaning. The frequency varies and is site-specific, and may vary from 6 months to 2 years. It is almost always necessary to dewater tanks to clean diffusers and down time is rarely less than a week, which means plants must have redundant tanks or ways to reduce plant load during cleaning
- The choice between fine and coarse often depends on the plant’s ability to clean diffusers. If cleaning is not possible, fine poor diffusers are a very poor choice.

Coarse Bubble

- Coarse bubble diffusers were, in former times, installed in simple rows, which created a kind of spiral roll across the tank. Additional rows of diffusers created cross roll or “ridge and furrow” flow patterns.
- Modern coarse bubble installations place diffusers as uniformly as possible across the floor of the tank. These systems, called “full floor coverage” are significantly more efficient that a cross roll configuration.
- Full floor coverage can provide as much as 3%/m SOTE while a spiral roll system may be as low as 1%/m.
- Both systems create large circulating liquid velocities in the tank, as much as 2m/sec at the surface

Examples of Coarse Bubble Geometries



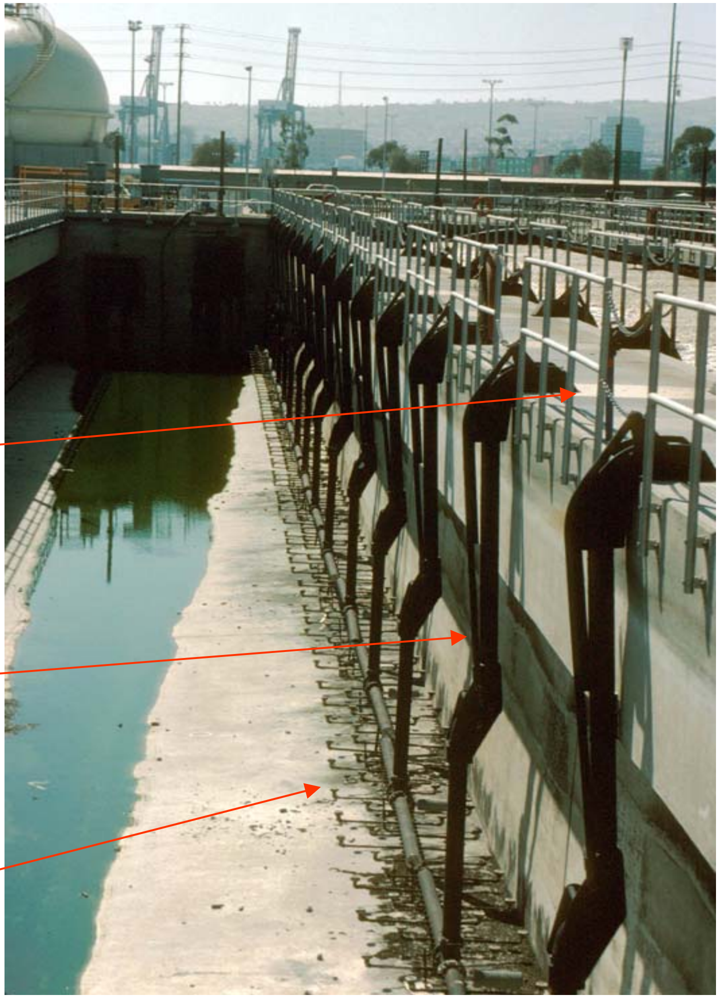
Red lines show fluid flow. Surface swells may be 200 mm high.
Fluid velocities may be greater than 2m/sec in some areas.

Empty Aeration Tank with Spiral Roll Diffuser System using Swing Arms to facilitate Maintenance

Cut off valve under the deck for each arm

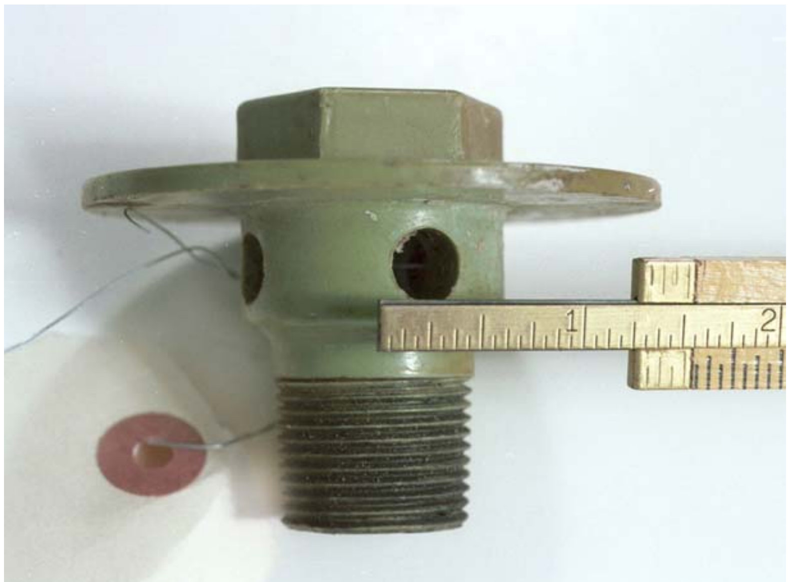
Swing Arms, with knee joint

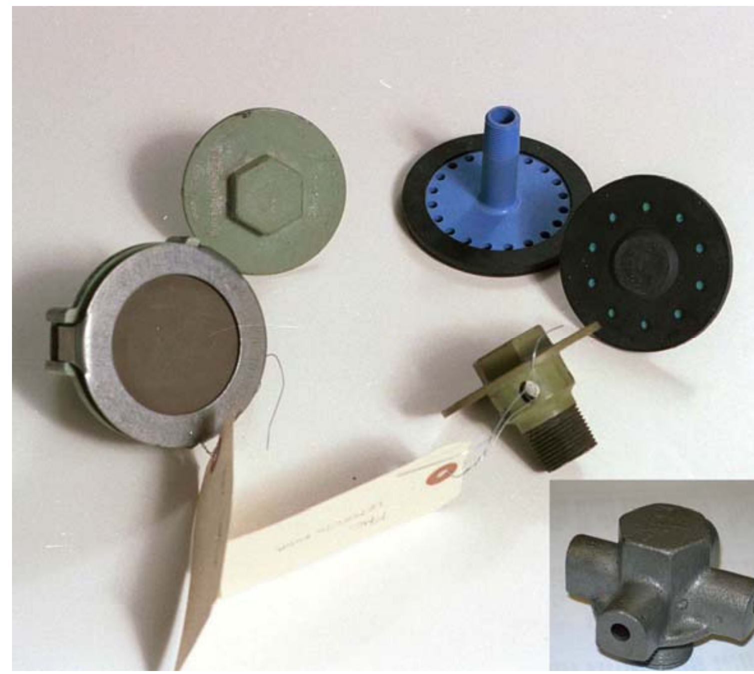
Spargers



Swing arm in upper Position exposing diffusers

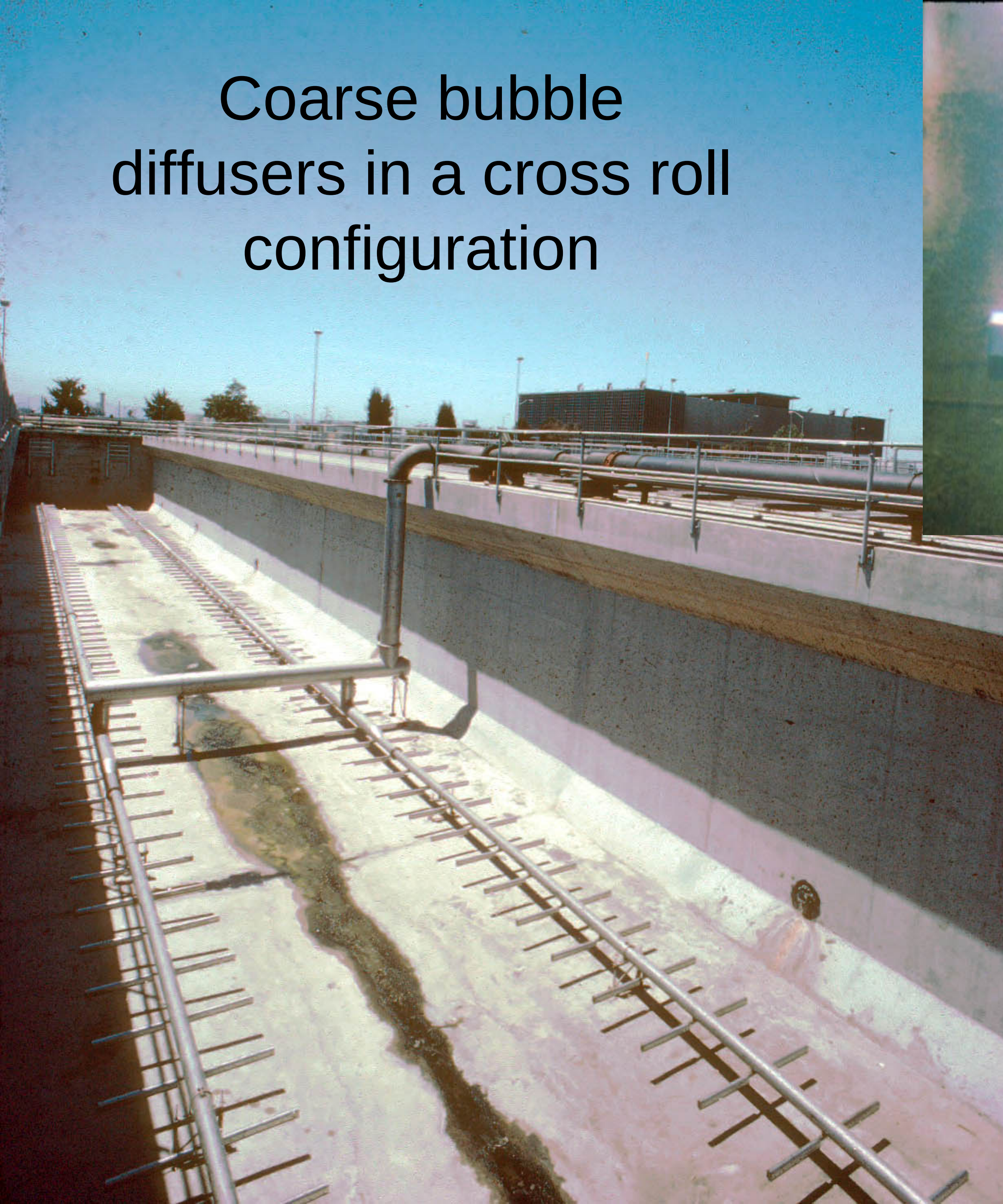
Sparger Collection

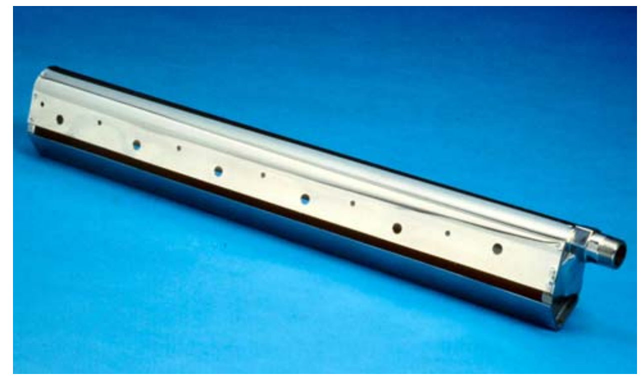




A sparger is a type of coarse bubble diffuser as shown here. The orifices are ~ 10 mm. Early spargers were made of low-carbon steel, very heavy and expensive (lower right) while new spargers are plastic with rubber covers (upper right)

Coarse bubble diffusers in a cross roll configuration





This type of diffuser is now sold by many companies. At low air flow, only the small orifices are used. As air flow increases the larger orifices then the slots pass air.

Fine Pore Diffusers

- Fine pore diffusers are called fine pore, as opposed to fine bubble, to indicate that the fine bubbles are created by a porous media, such as a ceramic stone
- Other devices, such as turbines and jets, can produce fine bubbles by hydraulic shear
- Fine bubble diffusers dominate the market place in Europe and North America. They save more than half the power required of coarse bubble diffusers, and are more efficient than surface aerators as well, although surface aerators still have preferred applications (e.g., HPO Activated Sludge).
- Fine pore diffusers in new installations are always mounted in full floor configurations. For retrofits, fine pore tube diffusers have been mounted on swing arms and air headers

Fine Pore Diffusers are Manufactured in a Variety of Geometries and Materials

- Materials
  - Ceramic
  - Sintered plastic beads and pellets
  - PVC (now obsolete)
  - Polyurethane (several manufacturers)
  - EPDM (rubber - *ethylene propylene diene monomer)*
  - Silicone
- Each material has advantages and disadvantages
  - The organic materials may interact with the wastewater, swelling if the absorb solvents or hardening and shrinking if they leach their components into the wastewater
  - PVC had severe shrinking and hardening problems and it virtually out of the market
  - EPDM is a blend – hence each manufacturer may provide a unique blend, always a proprietary formula, and it is difficult to make comparisons
  - Silicone has been used less in the United States, more so in Europe. The net result is there is less overall experience with silicone
  - Ceramics (high fire, low fire) have been used for more than 70 years for diffusers, but are heavy and often require a more expensive piping system (especially ceramic tube diffusers)
- Orifices
  - The organic materials have punches, usually only ~1 mm long and the width of a knife blade, and there is always a punch pattern and a finite number of punches. The long axis of the punch is particular to the expansion direction of the diffuser. The punches are of uniform size.
  - Ceramics have essentially an infinite number of pores and the size varies

Geometries

- Ceramic domes (~ 170 mm dia)
- Ceramic discs (~ 220 or 170 mm diameter)
- Membrane discs (~220, 170 mm dia and sometimes larger)
- Ceramic tubes (50 mm dia by 360 mm long)
- Membrane tubes (50 to 100 mm dia by 360 to 720 mm long)
- Membrane panels (usually polyurethane, 1 m wide by 4 m long)
- Membrane strips (usually polyurethane, 20 mm wide by 4 m long)

Membrane tubes and strips can usually be obtained in custom lengths and diameters

Fine Pore Diffusers

Clockwise from the upper right: two new ceramic domes, high fire and low fire; fouled ceramic domes, showing modest air side fouling and server liquid side fouling; grid of ceramic discs, showing full floor geometry, and membrane panels.

Fine Pore Tube Diffusers

Five different tube diffusers:
(left to right)

EPDM tube
PVC tube
Ceramic tube
EPDM tube
Sintered plastic tube

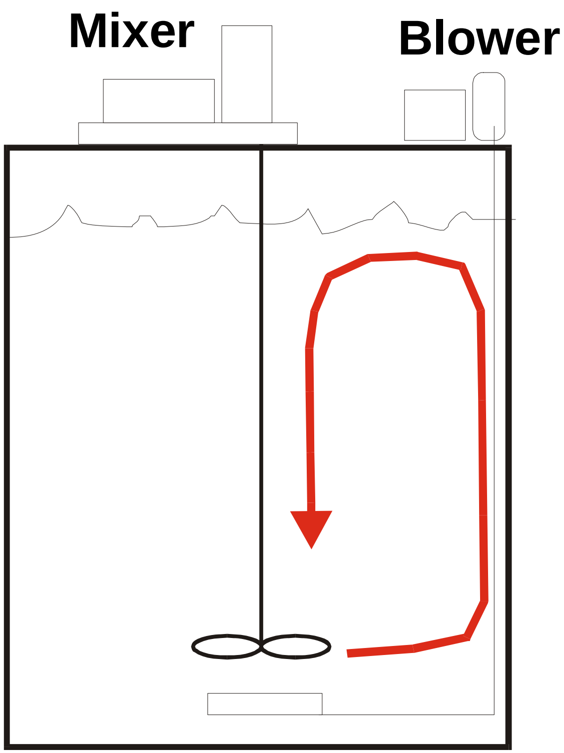
Pressure drop

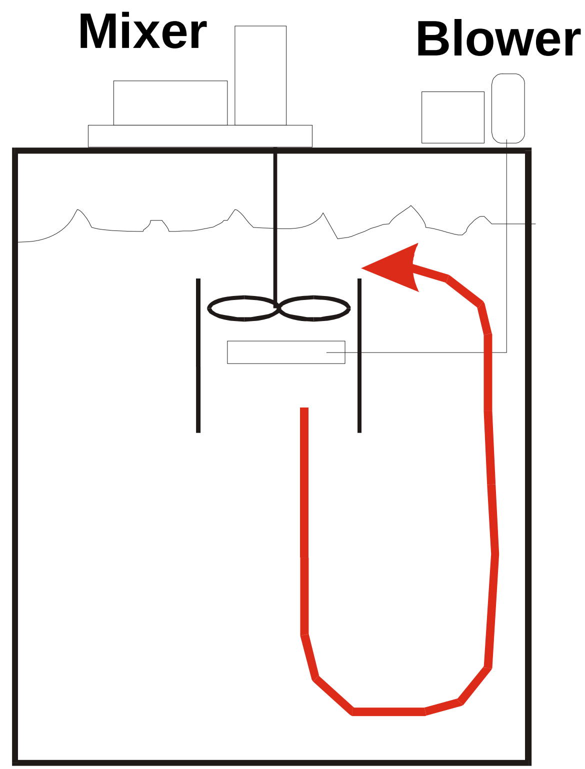
- Both coarse and fine bubble diffusers present a pressure drop. The operating pressure of a diffused air system must include pressure drop in pipelines, the hydrostatic pressure of the water at the diffuser submergence, and the pressure drop of the diffuser.
- A diffuser pressure drop is called the “dynamic wet pressure” and includes both the pressure loss through the diffuser but also the surface tension of the fluid being aerated.
- Coarse bubble diffusers have very low DWP, generally only 5 to 10 mbar. Fine pore diffusers always have more, with ceramic devices having DWPs from 15 to 30 mbar. Membrane devices have higher DWPs, as much as 45 mbar. Consultant manufacturers data and verify DWP when clean water testing
- Fouled diffusers have much higher DWP. The DWP of a fouled diffuser can be more than twice its new DWP.
- When diffusers are highly fouled, several undesirable results are likley:
  - The diffuser, especially if it is a membrane diffuser, may rip or tear away from it’s binding
  - Centrifugal blowers may go into surge as the pressure increases beyond the safe range
  - The motors on positive displacement motors may overload and burn out.
  - In all cases, the transfer rate of the diffusers decreases and the treatment plant may be unable to maintain its rated capacity

Combined Types: Diffusion and Mechanical Shearing

- There are several types of aerators that use a combination of bubbles and mechanical energy to create fine bubbles without using small orifices
- Turbines are one major example, that use an impeller to shear coarse bubbles into fine bubbles
- Jet aerators are another type, which inject air into the throat of a Venturi to create fine bubbles
- There are other less common types, such as impeller blades that aspirate air into a discharge plume, rotating blades with porous surfaces, etc.

Turbines 1



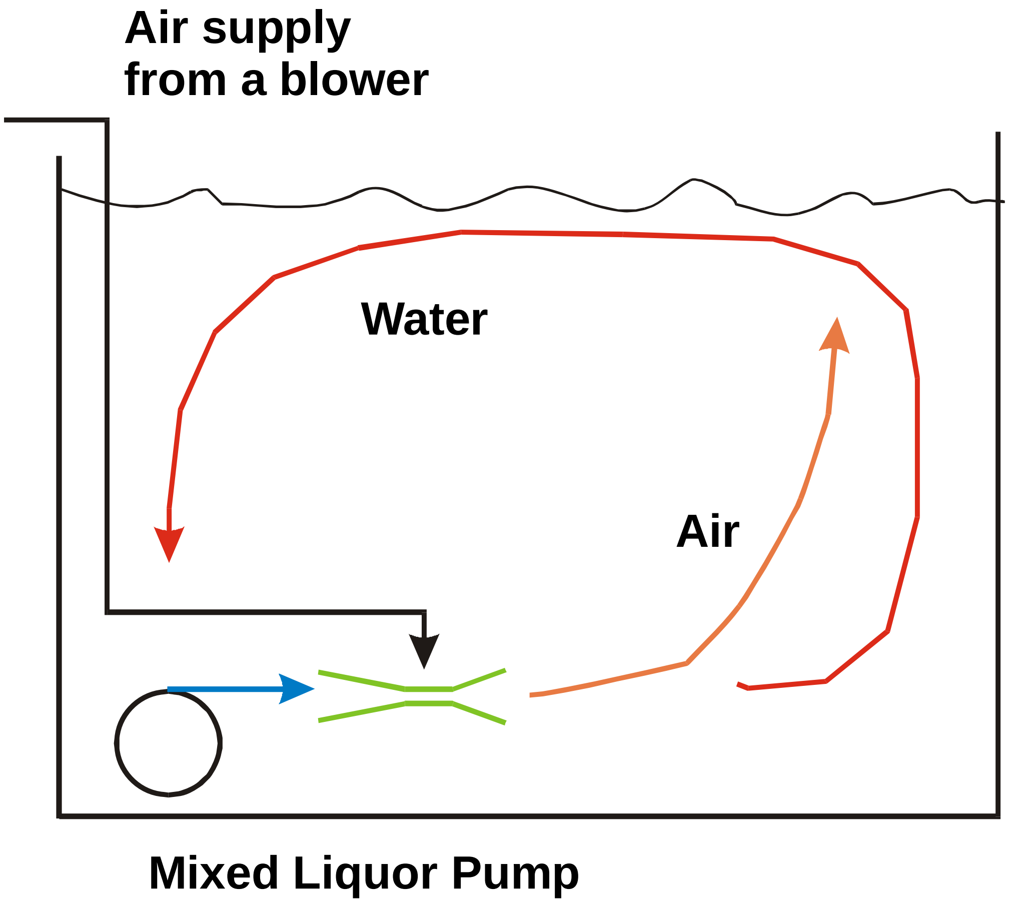


Two types exist: A sparged turbine (left) uses the impeller to break the bubbles as it forces them away from the sparge ring and towards the wall. The downdraft turbine (right) uses the downward fluid velocity to carry the bubbles to the bottom of the tank

Turbines 2

- Turbines are commonly used in new treatment plant designs. The exception can be industrial designs, where a very high OUR must be satisfied.
- Turbines can have high SOTE, but are generally lower than surface aerators in SAE. The reason is the penalty associated with two prime movers – blower motor and mixer motor
- Finally, turbines make fine bubbles and have low alpha factors, like fine bubble diffusers. They do not have fouling problems.

Jet Aerators



Jet aerators find application in industries and have rarely been used in municipal treatment plants. They have low alpha factors like fine pore diffusers, generally do not foul and suffer low SAEs due to the need to pump water and compress air

Efficiency Summary

- The following slide shows efficiencies of various aeration devices in conditions generally typical of municipal wastewater treatment plants. Three columns are provided: The left most is the clean water aeration efficiency or SAE.
- The next two columns show process water efficiency, at 2 mg/L DO concentration. Two columns are needed since the efficiency of fine pore and fine bubble devices will vary with SRT. Long SRT systems remove surfactants more rapidly, which elevates the alpha factor.
- The data in the table are supported by published tests, but there can be site-specific considerations that alter the results. The table results should not be used as a general guide line and not for design. Aeration efficiency should always be verified by transfer testing.

Efficiency

Aerator Type	SAE kg_{O_2} kWh^{-1}	Low SRT AE (@ 2 mg_{DO} l^{-1})	High SRT AE (@ 2 mg_{DO} l^{-1})
High-speed surface aerator	0.9–1.3	0.4-0.8	
Low-speed surface aerator	1.5–2.1	0.7–1.5	
Coarse-Bubble	0.6 –1.5	0.3-0.7	0.4-0.9
Turbines or jets (Fine-bubble)	1.2-1.8	0.4-0.6	0.6-0.8
Fine-Pore (Fine-bubble)	3.6–4.8	0.7–1.0	2.0–2.6

Air Blowers 1

- Blowers are compressors operating at low pressure and are needed for all subsurface aeration systems.
- Blowers often restrict the flexibility of an aeration system, due to their limited “turn up” and “turn down” range.
- There are generally two kinds of blowers: positive displacement (PD) and centrifugal.

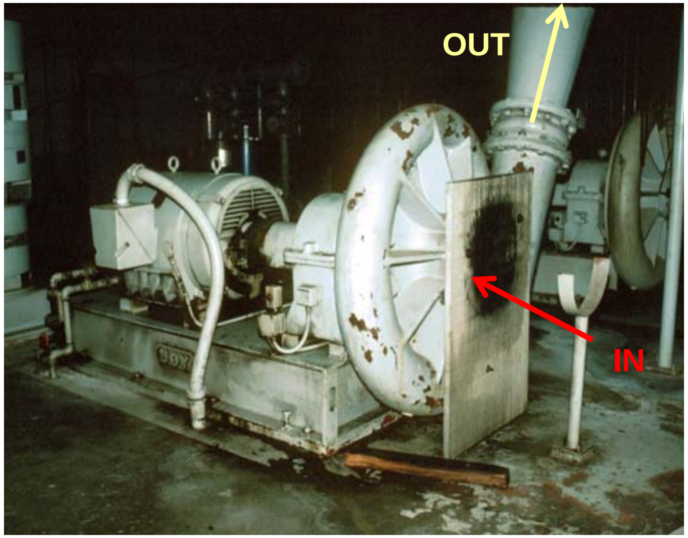
Air Blowers 2

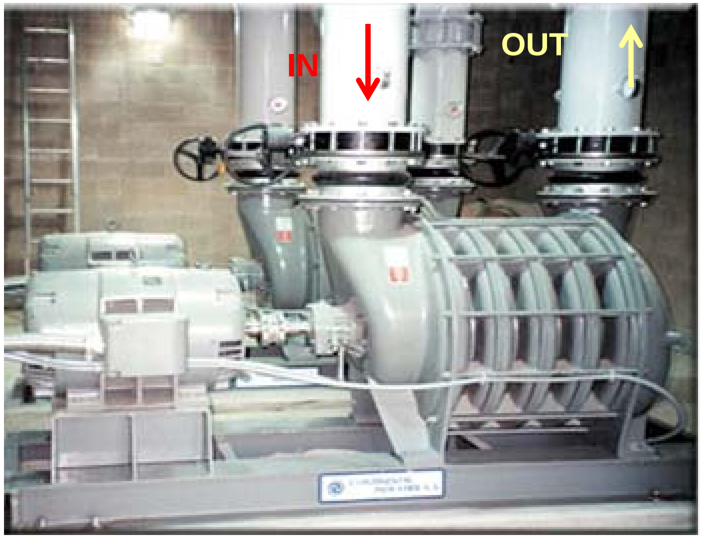
- PD blowers are generally considered constant flow, variable pressure devices
- Centrifugal blowers are considered constant pressure variable flow devices
- The same PD blower can be operated over a large range of pressures, requiring only a larger motor to operate at higher pressure.
- It is more difficult to change the pressure of a centrifugal blower. New types have inlet guide vanes and outlet diffusers which provide a larger range.
- When treatment plants are upgraded from coarse to fine pore diffusers, a frequent problem is oversized blowers that operate at too low a discharge pressure. This occurs because the air requirements are much less, but the pressure drop (DWP) of the fine pore diffusers is high. A detailed blower analysis must be performed if the existing blowers are to be reused.

Air Blowers 3
A Comparison of Types

Positive Displacement	Centrifugal
• More economical at small scale	• Economical at all scale but especially for large installations
• Noisy – the low frequency “thud” associated with the rotary lobes is harder to dampen. Three lobe blowers partially overcome this objection	• Also noisy but the continuous, higher frequency spinning sounds are easier to dampen.
• Vibration transmissions to piping and supports sometimes problematic • Motor overloads with excessive discharge pressure, requiring current protection on motors • Higher discharge pressures possible	• Operation at excessive flow overloads the motor, and operation at excessive pressure causes surge, which may result in destruction of the blower. Over current and vibration detection controls are required for safe operation

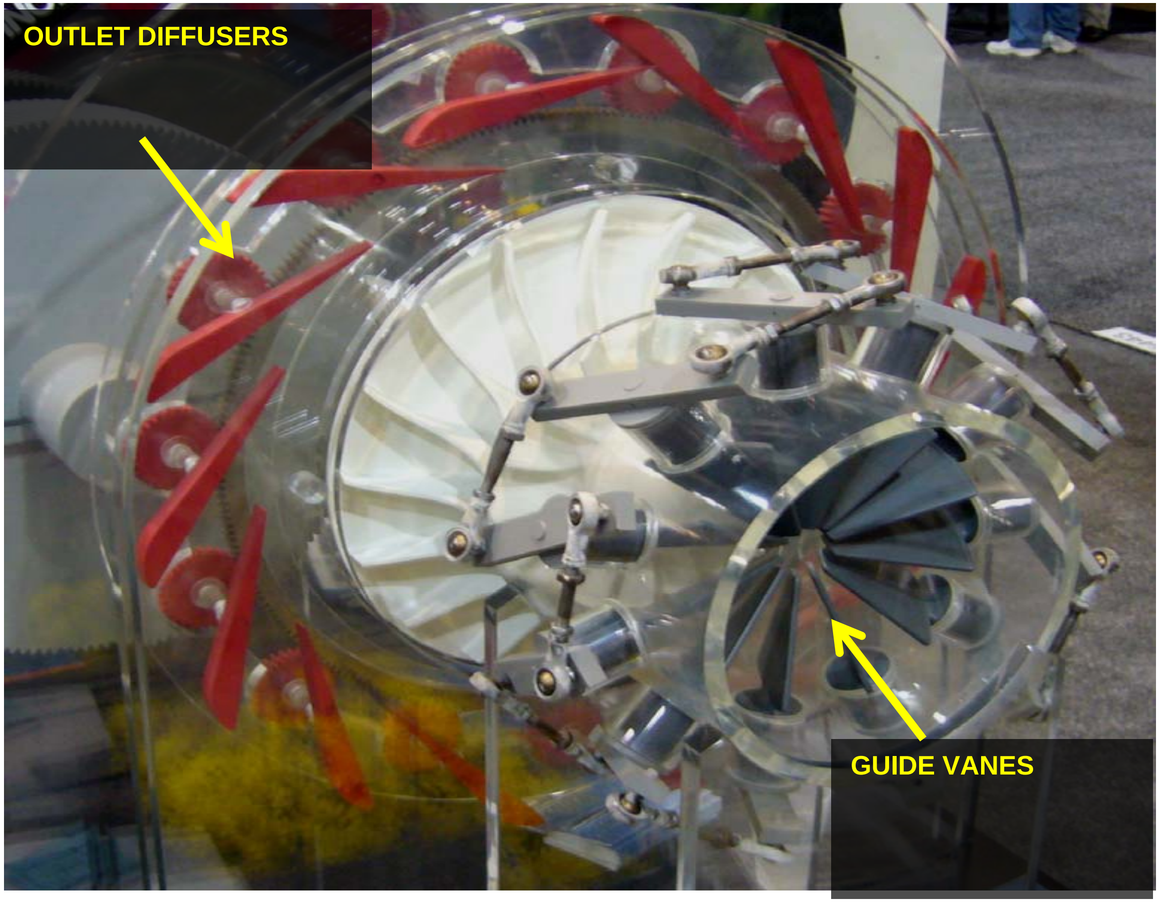
Two Types of Centrifugal Blowers



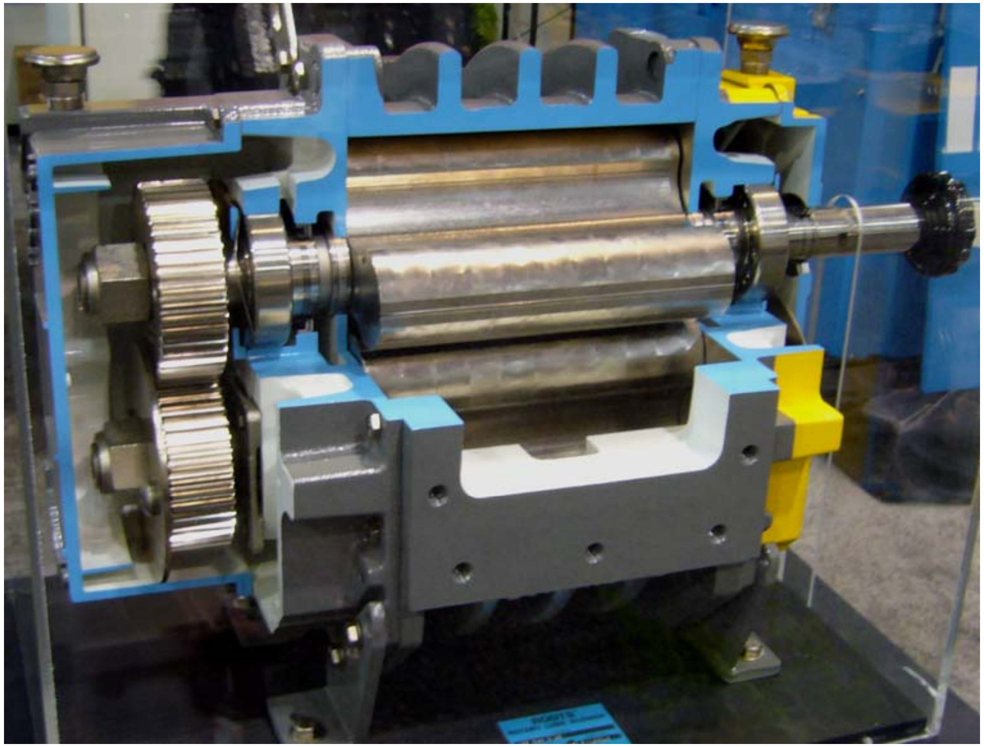


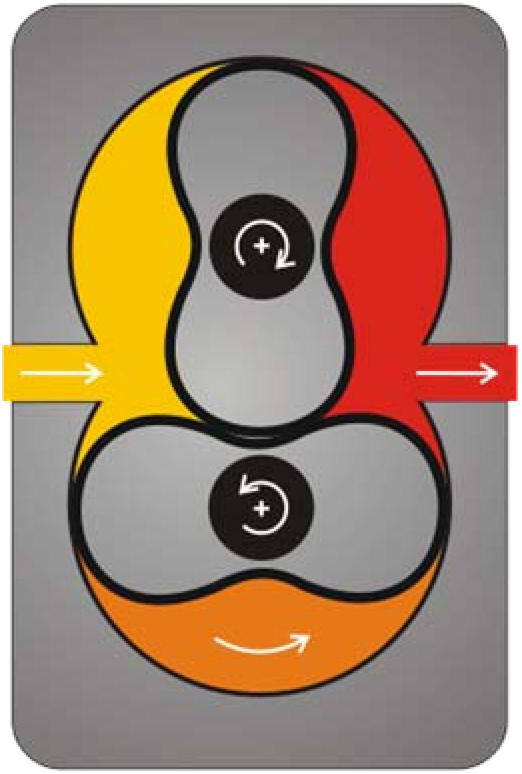
Single stage centrifugal blower on the left, operates at ~ 12,000 RPM or higher, requiging a step up gear box. Multistage centrifugal on the right operated at 3600 RMP and requires no gear box. Modern single stage centrifugals with inlet vanes and outlet diffusers and considered the most efficient, but are expensive and generally justified only for larger plants

Guide Vanes and Inlet Diffusers



Positive Displacement Blower





PD blower on the left and schematic on the right. PD blowers can be used for higher pressure installations.

Blower Specification

- Blower specification is a most important task. Blowers are among the most expensive equipment purchased for a treatment plant and require trained mechanics for maintenance.
- Often consulting firms will have a single individual or a sub consultant to work with blower specification

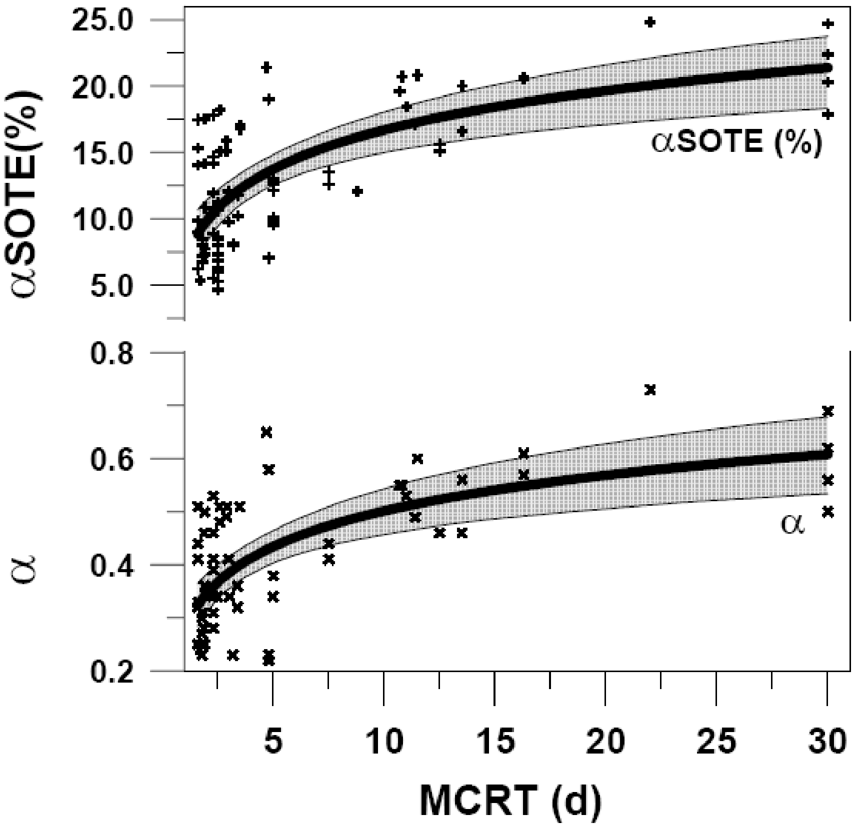
Converting Clean Water Transfer Rates to Process Transfer Rates

- Converting clean water to process water transfer rates involves several straight forward equations that use parameters such as DO, temperature, barometric pressure, humidity.
- Two water quality parameters present more difficulty.
- The first is the Beta factor, or the reduction in oxygen equilibrium concentration (saturation concentration at the operating hydrostatic pressure) due to contaminants in the wastewater. The modern approach is to use the salinity of the wastewater, which is easily measured and use “handbook” salinity versus saturation tables.
- The alpha factor is more difficult. It ranges from 0 to 1.0 (values greater than 1.0 can be obtained in laboratory situations with small vessels or in sea water without surfactants).

Alpha Factor 1

- There is a great deal of research, none entirely conclusive on alpha factors. We have performed a large fraction of this work.
- The mechanisms and theory of transfer rate reduction due to surfactants is beyond the scope of this course, but we refer you to some of our recent publications
- The following figure shows the essence of what we have learned and how it affects treatment plants.

Alpha Factor 2



This figure shows the alpha factor (bottom) and the αSOTE (%, top). For treatment plants operating at low MCRT, alpha factors are supressed, and may average 0.3. The range shown in the figure is associated with new (higher values) versus old (lower values). At high SRT the alpha factors increase.

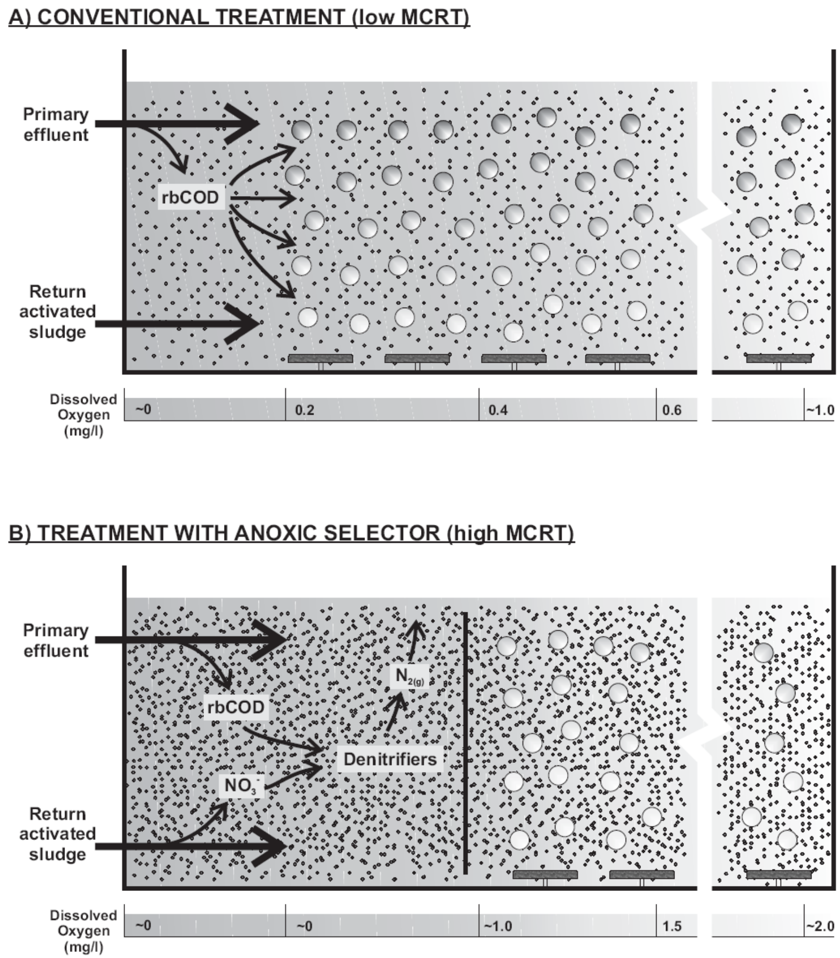
Alpha Factor 3

- The reason for the increased alpha at high MCRT is the more rapid and efficient removal of surfactants. It is easily observed in “plug flow” aeration tanks.
- In plug flow aeration tanks, the alpha factor at the influent zone of the aeration tank may be only 0.3 but at the effluent zone it may be as high as 0.8
- This dramatic change requires aeration tapering. Unfortunately, the alpha factor is lowest where the uptake rate is highest.

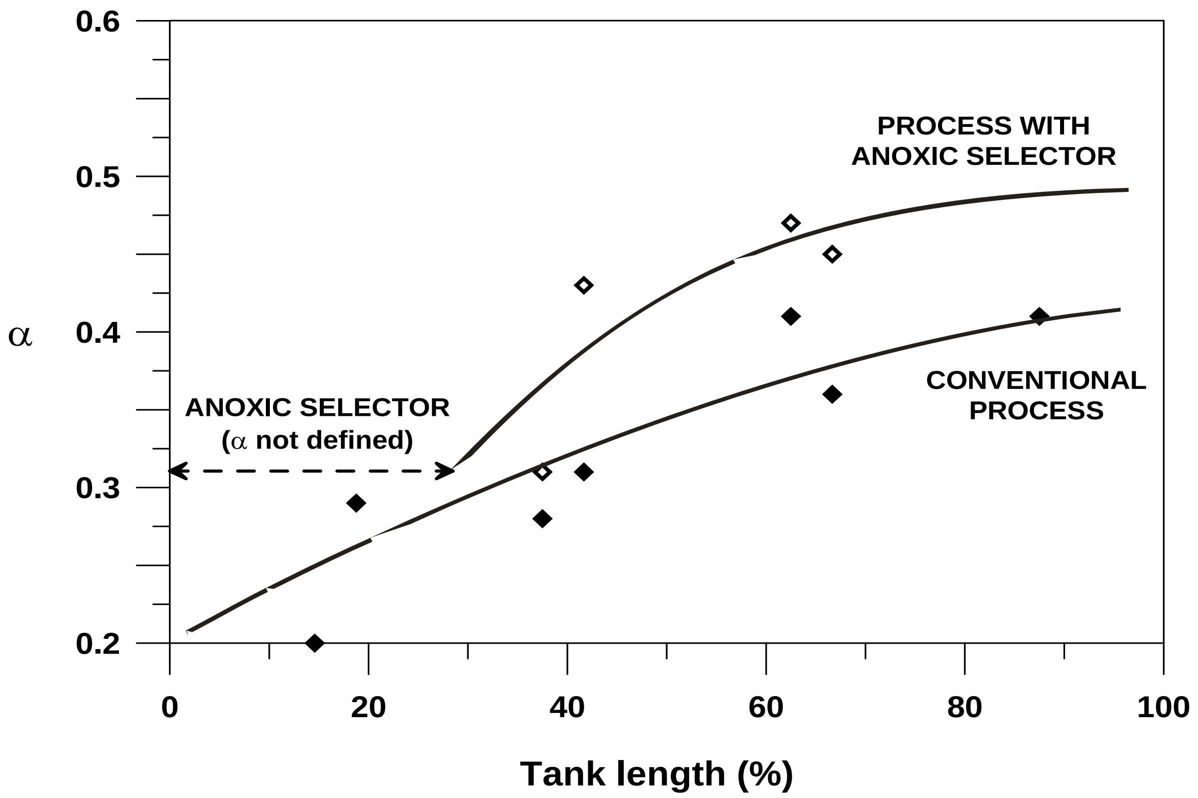
Role of Selectors

- Almost all modern activated sludge designs include a selector. In the past 15 years this innovation has become a stardard feature.
- For high SRT plants anoxic selectors denitrify, participate in phosphorous removal and prevent the growth of filamentous organisms
- For low SRT plants they participate in phosphorous removal and prevent the growth of filamentous organisms
- In both cases, our data show they improve alpha factors, presumably by the uptake of soluble contaminants into the biomass

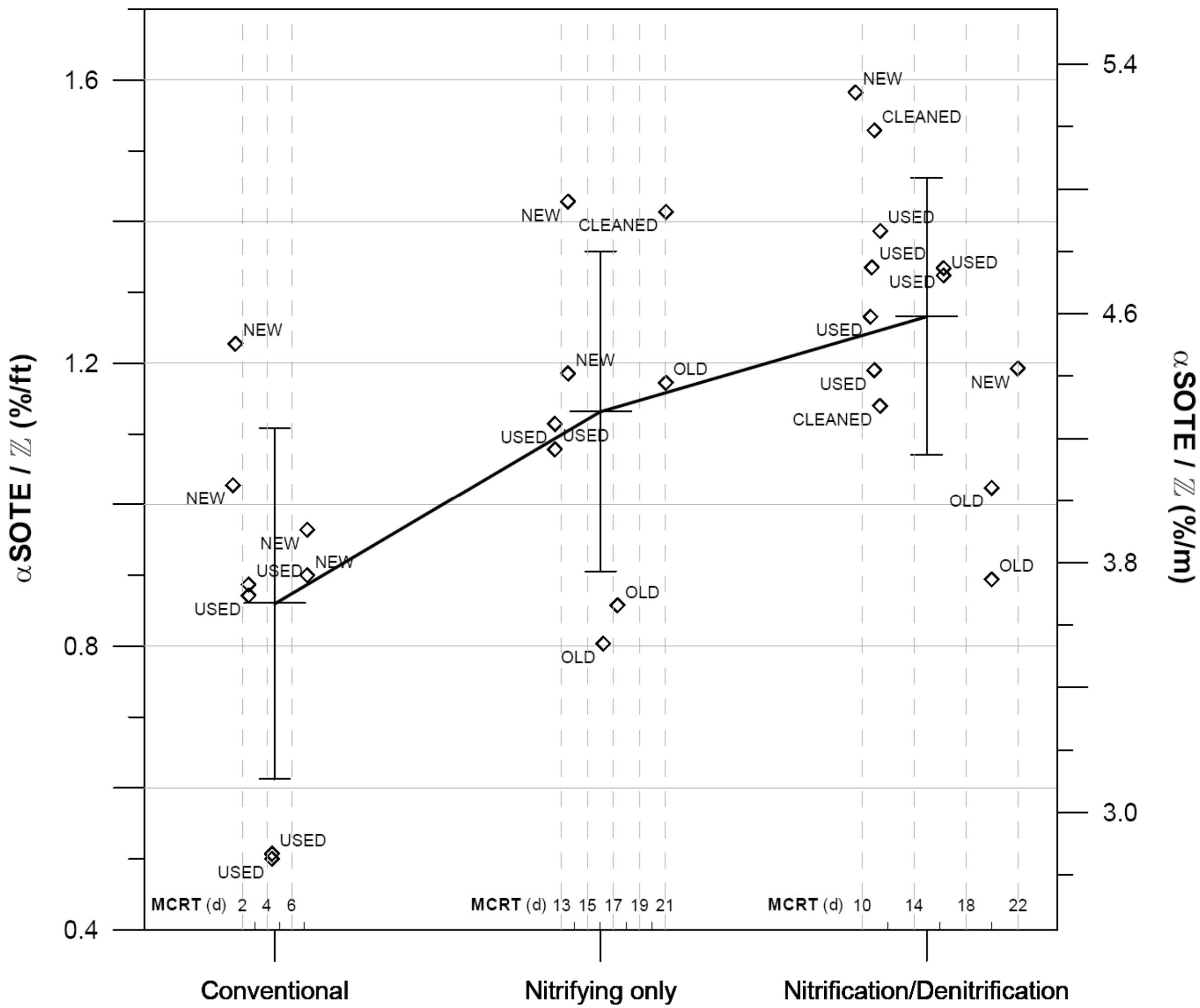
Schematic of Plant with and without selector



Impact of Selector and High MCRT on Alpha Factor



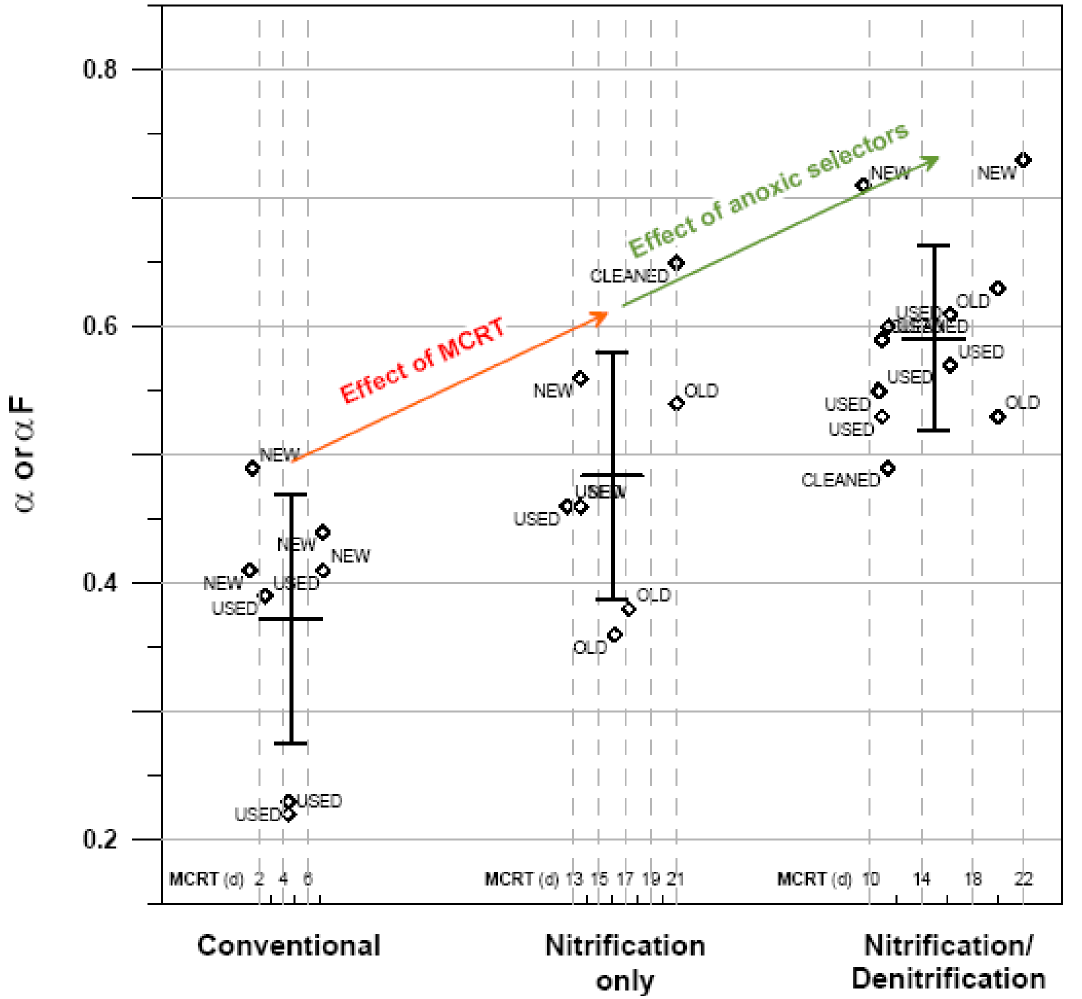
Summary of Transfer Rates at 100 Treatment Plants



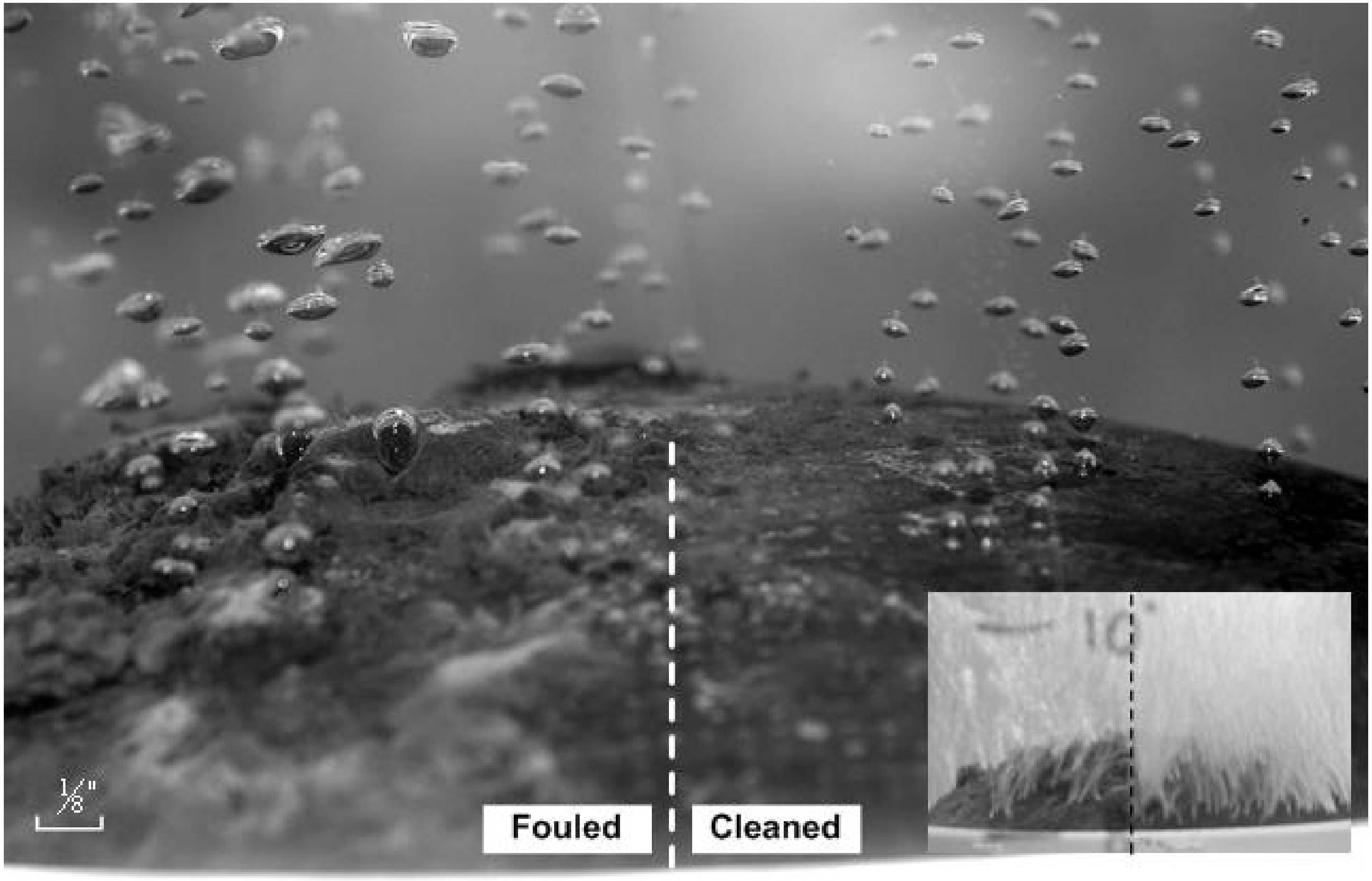
Normalized Standard Oxygen Transfer Efficiency for selected plants operating with different layouts.

Labels refer to the diffuser status: NEW (within 1 month from installation), USED (between 1 and 24 months of operation), OLD (over 24 months in operation), and CLEANED (within 1 month from a cleaning event). The effect of diffuser ageing outweighs the increase in performance due to process upgrade (from conventional to N-only and NDN).

Range of Alpha Factors in Treatment Plants



Photographic Evidence of the Effects of Diffuser Fouling

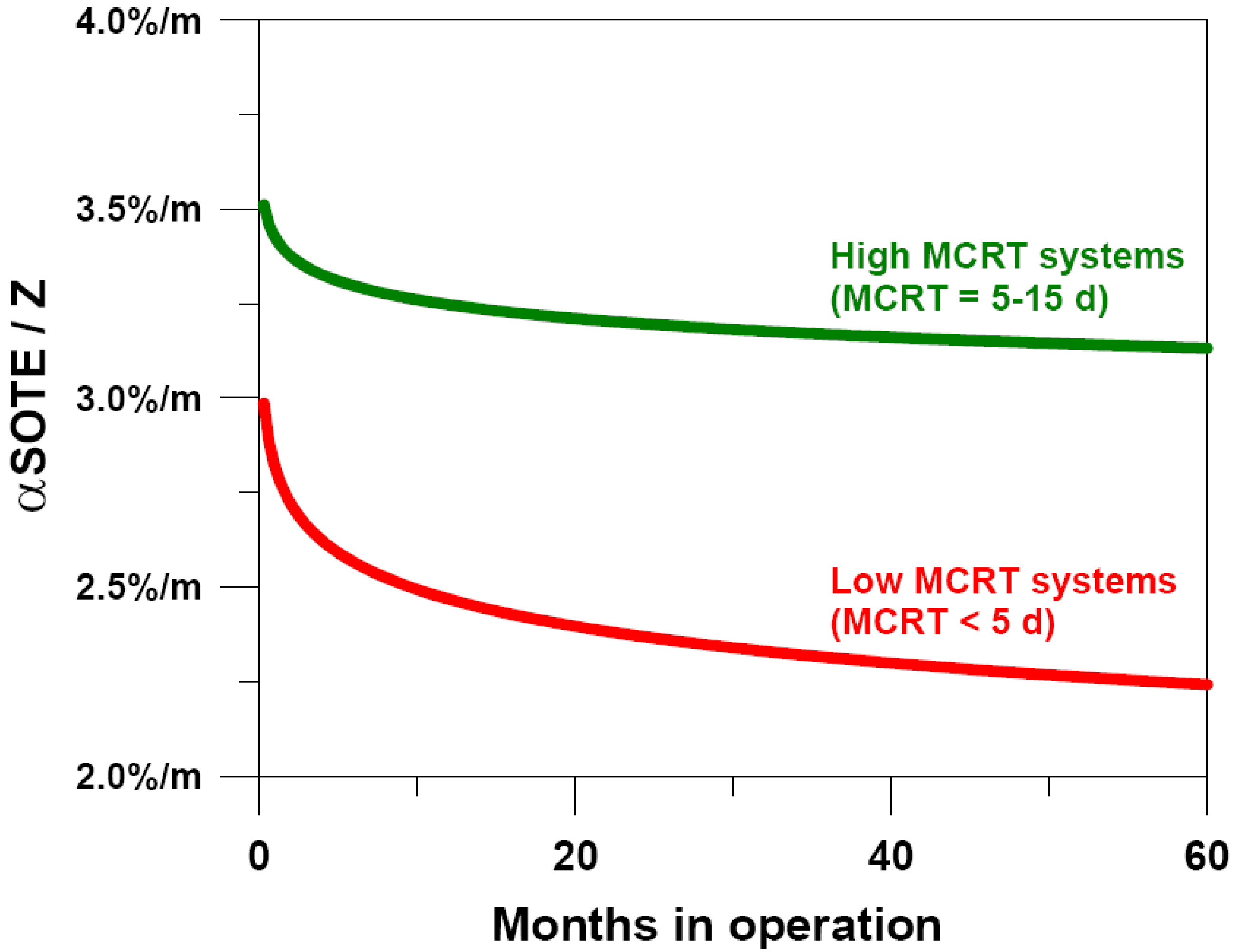


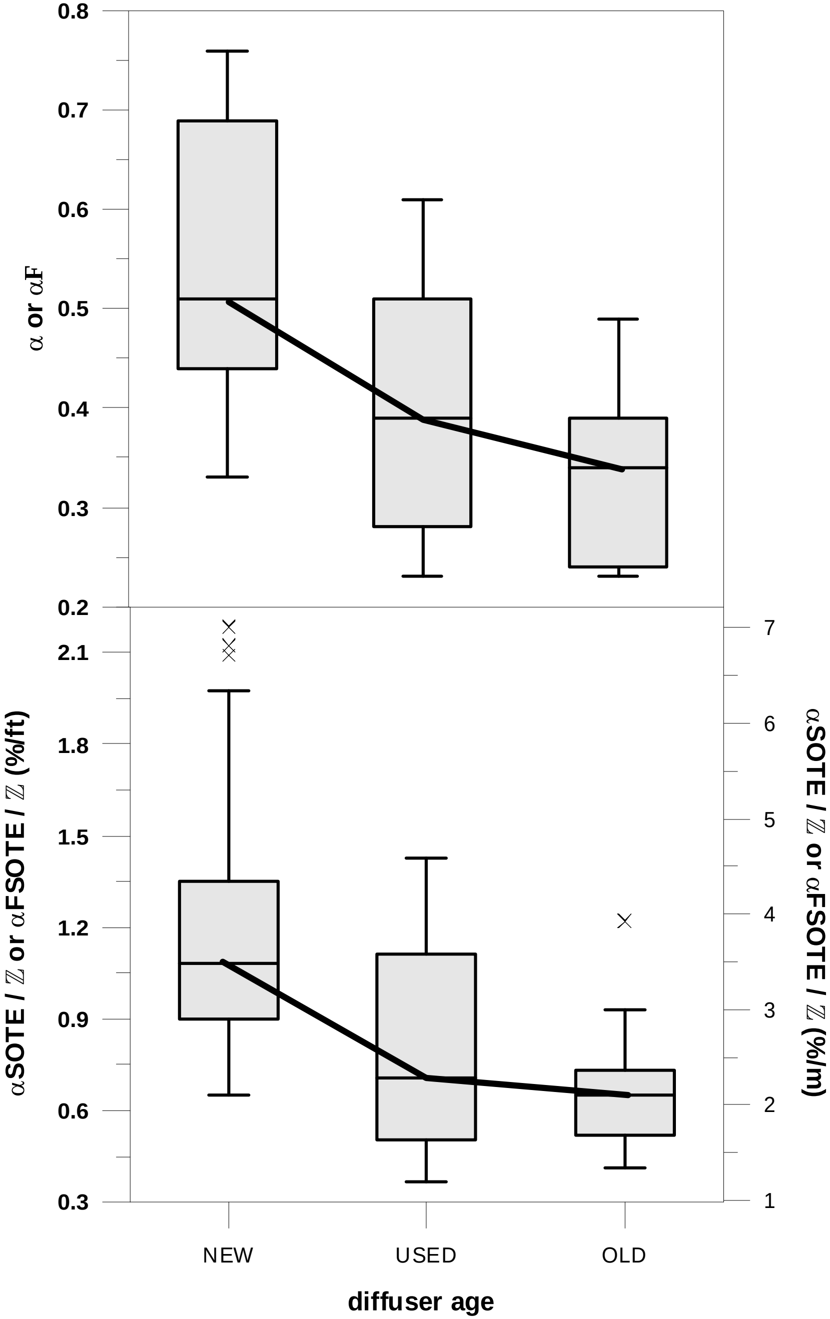
(Photo courtesy of Shao-Yuan Ben Leu).

Diffuser Cleaning

Observations of bioslim removal with simple tank-top hosing. On the left is a diffuser system exactly as it appeared after dewatering the tank. On the right is the system after partial hosing with reclaimed water, from the tank top.

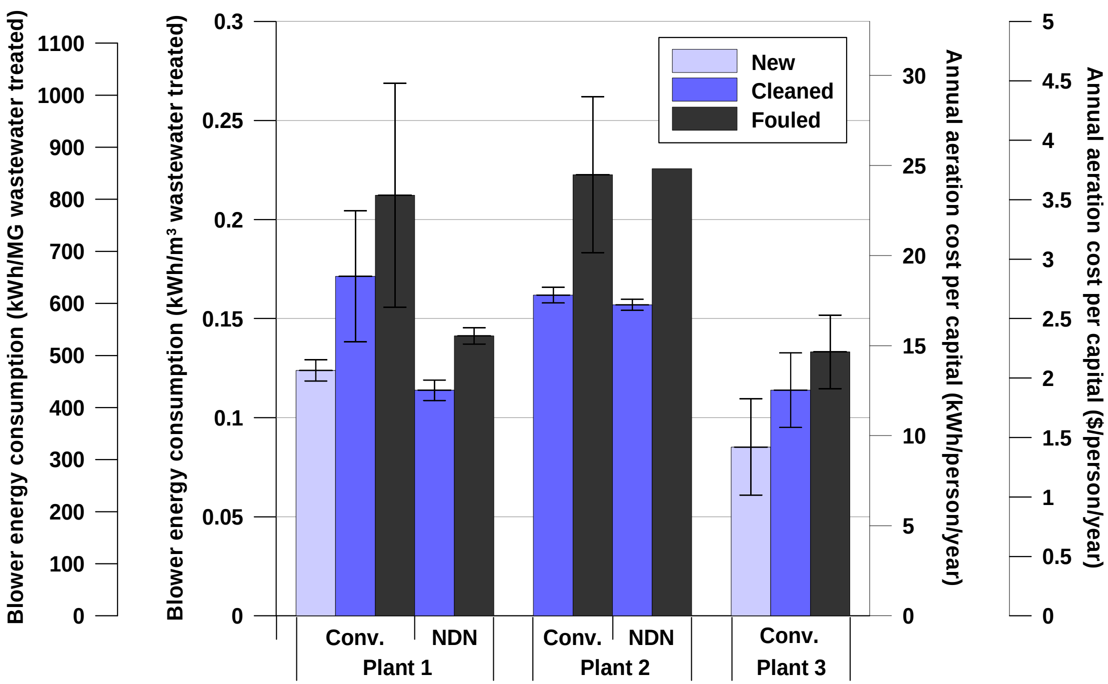
Fouling Rates for Low and High MCRT Plants





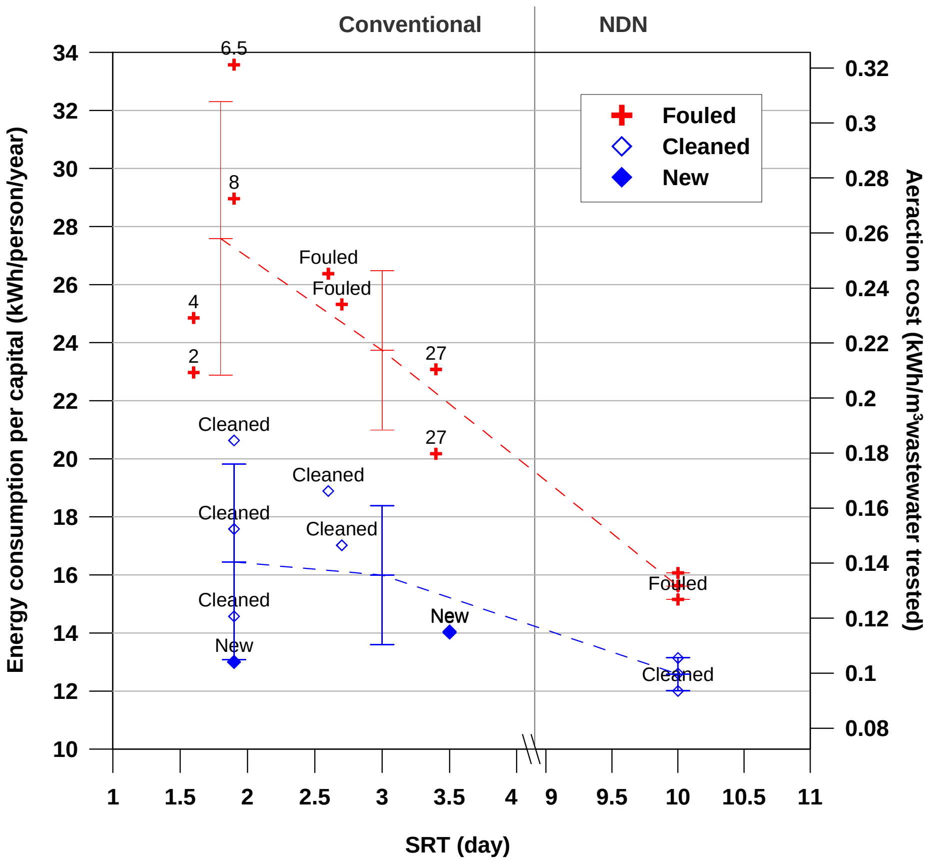
Example of Performance as a function of diffuser age and cleaning

An Example of Energy Conservation though Monitoring and Maintenance



Energy costs at three treatment plants. Plants 1 and 2 were converted from conventional to NDN operation. It is important to observe that the energy consumption per cubic meter of wastewater treated did not increase, due to the improved transfer at high MCRT. There were significant differences in energy consumption because of fouling which were recovered with cleaning. The design of Plant 3 was more efficient.

Energy Consumption for Various Conditions for Plant 1



This slide shows the energy cost per capita for fouled, cleaned and new fine pore diffusers. Note the large difference in energy consumption for fouled and cleaned diffusers. Also note that operation at longer SRT is not more expensive that at lower SRT. Part of the reason is that low SRT systems foul more and more rapidly.

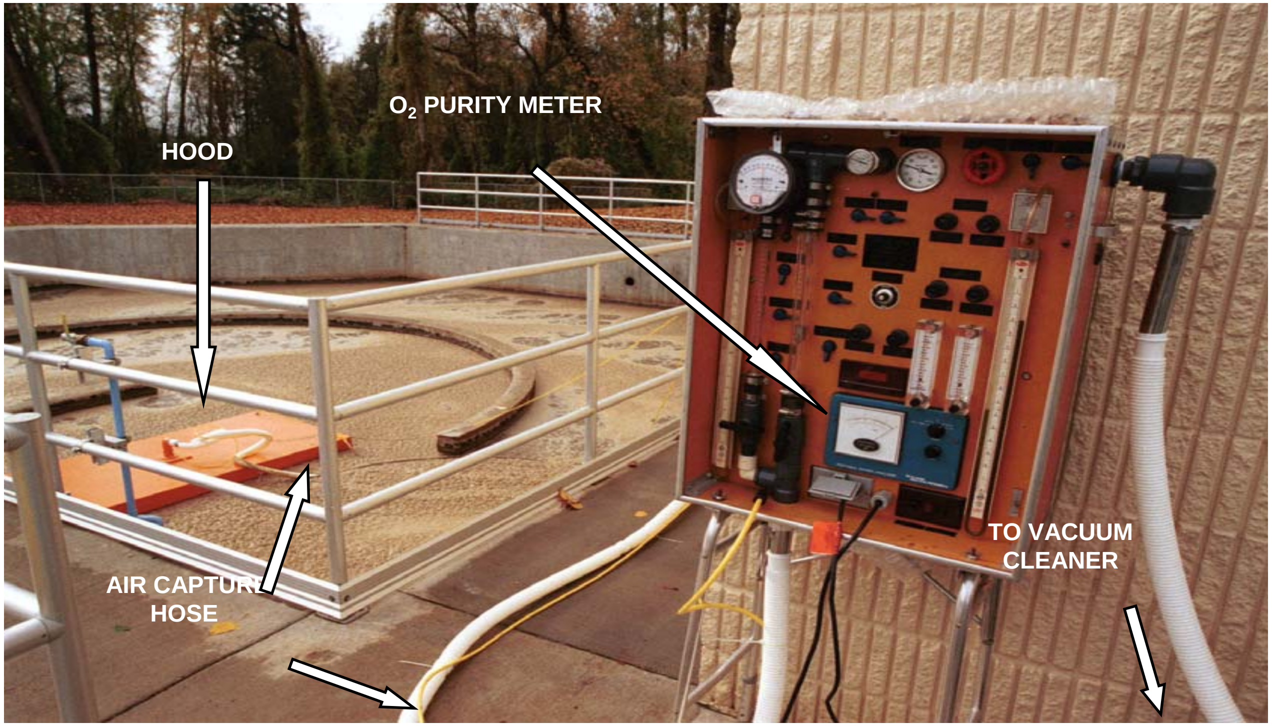
Performance Monitoring

- Aeration systems need to be periodically monitored to maintain transfer efficiency.
- For fine pore systems, the impacts of fouling must be monitored and diffusers cleaned or replaced as needed. The integrity of plastic piping systems must be assured.
- For coarse bubble systems, less monitoring is required, but system integrity must be evaluated – corrosion monitoring, structural monitoring.
- Blowers require routine maintenance and large blowers should be included in asset conservation programs.
- For surface aerators, motors, gear boxes and impellers must be periodically evaluated to track wear and avoid outright failures through preventative maintenance.

Fine Pore Systems

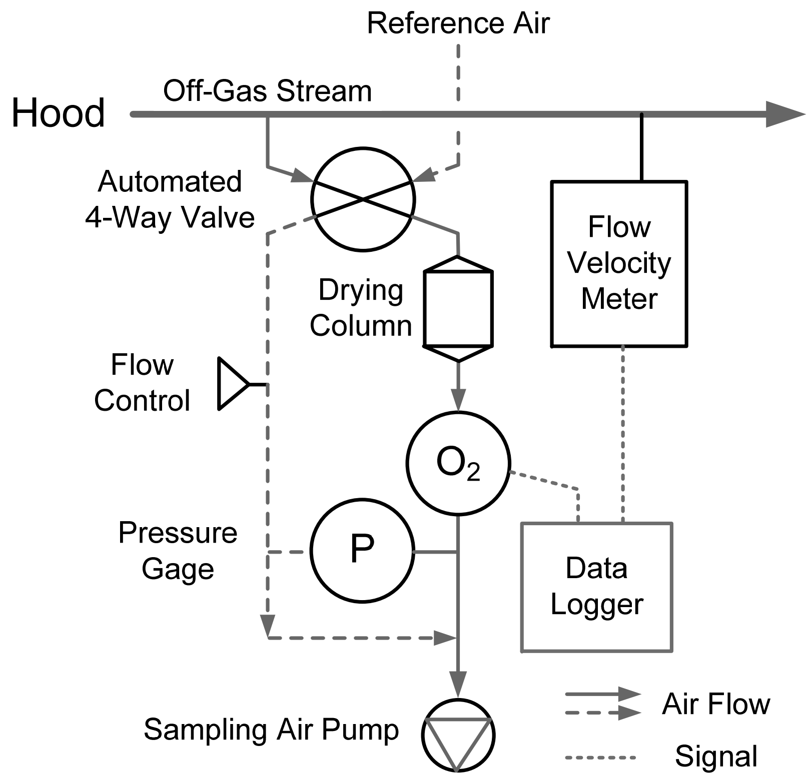
- Off-gas testing to determine transfer efficiency and OUR is one of the key ways to monitor system performance
- Sample diffusers, collected from aeration tanks, should be routinely analyzed for pressure drop, fouling and changes in material properties.
- System pressure should be tracked to predict when cleaning will be necessary

Process Testing Using the Off-gas Method



A floating hood is used to collect off-gas from many representative points on the aeration tank (at least 2% of the surface area should be sampled). The OTE can be measured using an oxygen analyzer and the air flux can be determined using the hood area and the off-gas flow rate. Overall tank averages are easy to calculate and it is also easy to obtain profiles in plug flow aeration tanks.

Off-gas Instrument Schematic

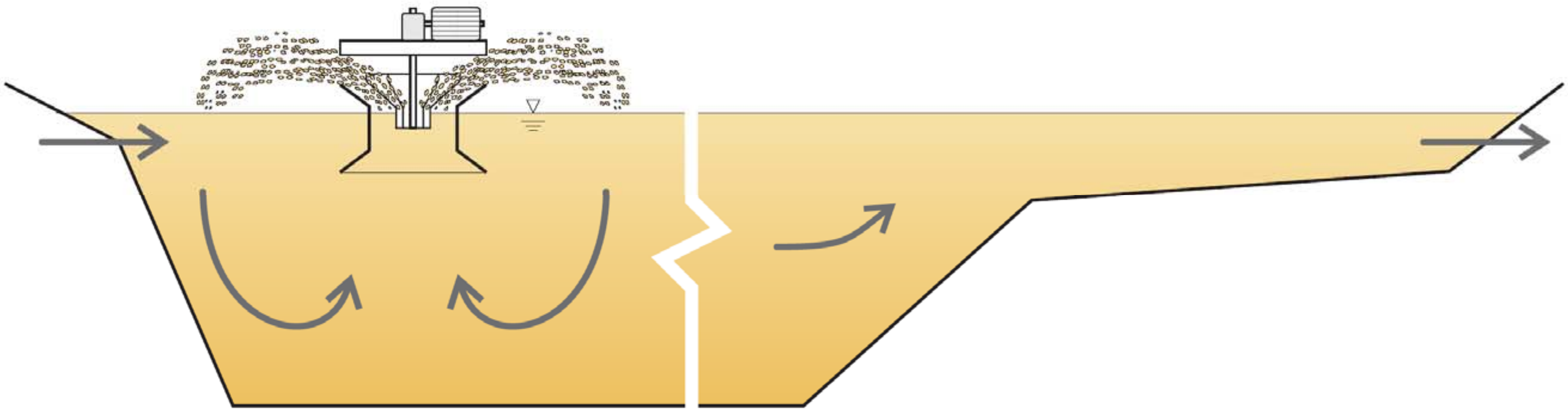


Off-gas, collected under the hood, is compared to atmospheric air to quantify the amount of oxygen absorbed in the liquid. The off-gas flow rate is measured in order to average the results across an aeration tank and to calculate plant-average transfer efficiencies. Oxygen is measured with a fuel cell

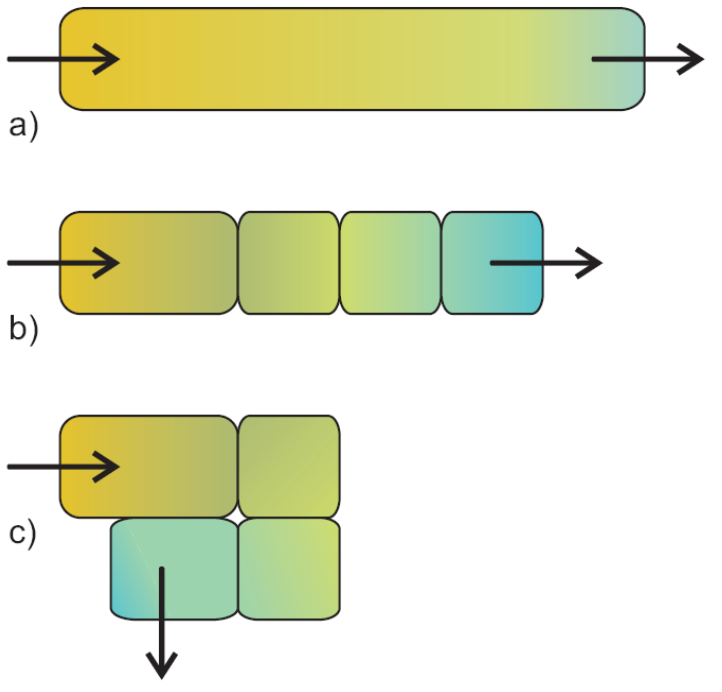
Sustainable Aeration Practices

- Lagoons typically find their best application in remote areas, where land is inexpensive and population density if low
- Such locations usually have fewer individuals trained to operate and maintain treatment plants.
- How does one perform mechanically simple aeration for lagoons and other treatment systems?

Lagoons Frequently Use Surface Aerators



Stage Aeration



By dividing large lagoons in to smaller cells or stages, it is possible to limit the amount of mechanical aeration and take advantage of natural aeration

Diffused Aeration

- It is now possible to used diffused aeration in large lagoons and install the equipment without dewatering the lagoon.
- Using a diffused aeration system has several potential advantages, including less heat loss, reduced misting and less impact from freezing
- Several manufacturers make competing equipment so a selection is possible.

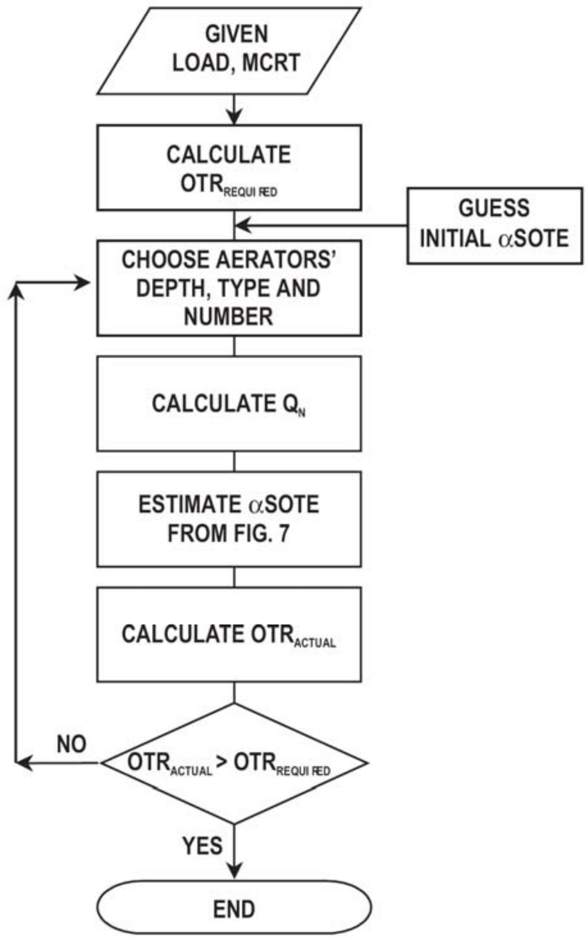
Diffused Aeration In Lagoons

Example of on manufacturer’s diffused aeration system for lagoons. On the left we see four membrane tube diffusers, on a “saddle” that allows the diffusers to be suspended above the bottom of the lagoon. The black vertical hoses convey the air as well as support the saddle. The picture on the right shows a full scale installation. The small white surf areas are above the diffusers. The air lateral floats on the lagoon surface

Design Algorithm

- A design algorithm has been developed to allow iterative solution of the dsign equiations (section 9.5) in the text
- The key variables are MCRT, and the “trial” air flux rate and the number of diffusers being used.
- The first step is to select a trial air flow rate based on eqn 7. AFR can be approximated by a “guessed” efficiency (αSOTE). The number of diffusers and the active or “bubbling” area of a single diffuser is used in eqn 7, along with the depth and number of diffusers.
- From Fig., locate the intersection of the MCRT and he normalized air flux, to obtain the αSOTE on the left axis.
- Check to see if the guess αSOTE matches the αSOTE you read from the left axis. It will take 2 or 3 iterations for the solution to converge. Vary either the SRT or the number of diffusers to iterate to convergence.
- Figure 9.35 in the text shows a flow diagram of the design process

Design Algorithm



Conclusions

- Aeration systems are key to the success of any biological process.
- They consume the most energy of any part of an aerobic process and the potential energy savings warrants close attention to design and maintenance details.
- The recent work at standardization of methodologies (ASCE standards) has taken a lot of the guess work out of the design process
- A key aspect of any design is its practicality and workability. One does not want to force the plant operators to operate in a certain way or region because of an inflexible aeration system

Conclusions

- Key concepts
  - Fine pore diffusers are the most efficient way of aerating municipal wastewater. They strip the fewest volatile organic compounds and cool the water less than other methods. They require routine maintenance
  - Coarse bubble diffusers are much less efficient – expect to use twice the energy of fine pore diffusers, but in spite of this disadvantage, they are sometimes the best solution. Examples were coarse bubble diffusers may be the best choice are for aeration of viscous fluids such as found in aerobic digesters and MBRs operating at high MLSS (> 8,000 mg/L). In plants where it is not possible to dewater the aeration tanks, coarse bubble diffusers my be preferred.
  - Surface aerators are less efficient but there are applications were they are the best choice.
  - Select aeration equipment not just on the basis of energy efficiency, but also on the basis of maintainability, odor production, and heat loss.

Additional Resources

- Our group has published more than 20 papers and even more reports on aeration. Many are available and all are listed on my website www.seas.ucla.edu/stenstro
- Good luck and please keep up with our new publications

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