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Optimizing aeration energy in wastewater treatment

Plant designers and operators can optimize energy efficiency by focusing on key variables within the aeration process, including aerators, operational considerations, blowers, and automation capabilities. ***Thomas E. Jenkins, Vikram M. Pattarkine,*** *and* ***Michael K. Stenstrom*** *explain the ways in which engineers can devise a comprehensive and effective program to optimize the entire aeration process.*

Aeration accounts for half the total energy consumed during aeration in secondary domestic wastewater treatment facilities using activated sludge; however the supply of oxygen to the biological process can be less costly and resource-intensive. As energy costs continue to escalate, plant operators and designers are finding ways to reduce these operating costs by optimizing energy efficiency. Fortunately, solutions and tools are available.

Literally hundreds of variations of the suspended growth activated sludge process operate throughout the world, as it is the most common method for secondary treatment of domestic wastewater. And the aeration process, a vital function within this type of wastewater treatment facility, must be considered as a complete system in order to minimize the total amount of energy consumed.

Energy conservation can be complex since many variables can affect efficiency such as the diffusers used to introduce air to the process, the operating conditions, and the performance of the blowers providing air to aeration basins. Further complication can result from the interaction between loading, aerator efficiency, and blowers. System analysis is manageable if each aspect is considered independently, followed by evaluation of the interaction between each aspect. A thorough study of all of these variables will help designers and operators devise a comprehensive and effective program for optimizing the aeration process.

The first step is to examine each of these factors when designing a new system or applying an energy conservation program. Second, the various options need to be evaluated for cost effectiveness. Finally, the individual components must be coordinated to insure compatibility with each other and with overall process requirements. Dramatic savings in energy consumption and cost can be achieved without compromise in process performance.

Aerators

Aerator efficiency measures the amount of energy required to provide oxygen to the biological process at specific conditions. Actual performance will vary in any given application, but higher aerator efficiency at standard conditions will generally result in better operating efficiency.

The proper selection of aerator type is perhaps the most critical step in optimizing aeration energy. The first choice is between mechanical aerators and diffused aeration.

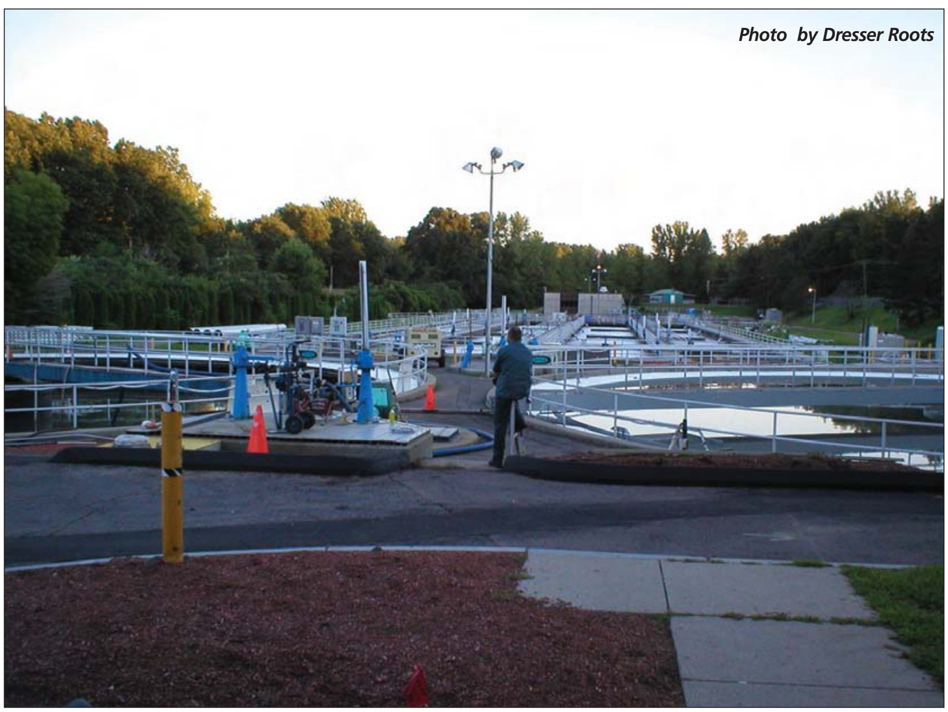
Although mechanical aerators are common, they are not capable of matching the efficiency of diffused aeration (see Table 1). Fine pore diffusers are generally displacing coarse bubble diffusers because of their improved efficiency. Proven technologies for fine pore diffusers have resulted in reduced maintenance requirements, extended life, and improved efficiency for both ceramic and membrane diffusers. Diffused aeration is generally the first choice for new systems and upgrades to existing systems. Elastomers have been developed for membrane type diffusers to provide long life and high oxygen transfer efficiency.

Diffuser efficiency is greatly influenced by the air flux rate, which is the airflow rate through the diffuser per unit surface area; therefore reducing airflow per diffuser area will increase oxygen transfer efficiency (OTE).

The airflow into the aeration basin must provide energy to keep the solids suspended. Mixing efficiency is also critical to energy efficiency, since it dictates the time allowed for contact between the bubbles and the mixed liquor. The arrangement of the diffusers within the basin should be carefully considered to promote thorough mixing. The general criterion for mixing in fine pore aeration systems is airflow per basin unit surface area. Field experience has shown that 1.46 $m^3/hr/m^2$ (0.08 CFM/sq ft) is usually adequate for maintaining mixing.

The need to provide good mixing and low air flux rates has pushed new designs to incorporate a large number of diffusers in the aeration basins. A large number of diffusers are spaced closely over the aeration basin floor, or long, closely spaced tubular diffusers are provided along the length of the tank wall. In other cases large panels or strips almost completely cover the floor of the aeration

Photo by Dresser Roots



Energy conservation can be complex to carry out in a wastewater treatment plant given the many variables that affect efficiency.

Aeration tanks at a wastewater treatment plant. *Photo by Dresser Roots*

Escalating enery costs are driving plant operators and designers to optimize energy efficiency of wastewater treatment plants.

basin. In upgrading or designing a new aeration system the energy efficiency must be balanced against initial equipment cost to provide the lowest total life cycle cost.

Adequate diffuser maintenance maintains oxygen transfer efficiency throughout the system's life. Over time biological fouling and mineral deposits will build up on the surface of fine pore diffusers, reducing OTE. It is necessary to periodically clean the diffusers to remove the fouling. The frequency will vary with the type of diffuser and actual wastewater characteristics. General cleaning every twelve to twenty-four months will restore the diffusers to nearly new OTE. Eliminating wasted power will generally offset the maintenance cost of cleaning, but excessive cleaning is not justified. Monitoring system pressure, observing the ratio of air flow rate to organic removal rate, or efficiency testing will allow the operators to determine the optimum cleaning frequency.

Over time the material in membrane diffusers can degrade, reducing flexibility and OTE. The compounds used in current diffuser manufacturing have been specifically developed to minimize this effect. Eventually membrane replacement may be required when cleaning fails to restore OTE sufficiently. Estimates of membrane replacement frequency developed in the past are no longer applicable. Careful analysis of actual performance, including the use of off-gas testing and monitoring power requirements, should be employed to determine the most economical replacement schedule.

Operational considerations

Operating conditions in the aeration basin influence oxygen transfer efficiency. The most significant factor, and one of the most readily controlled, is the dissolved oxygen concentration (DO) in the mixed liquor. High DO reduces the "driving force" moving the oxygen from the air bubble into the water. Operators have a natural inclination to operate at high DO to insure that the process is not oxygen limited.

A common misperception is that the process removal rate will improve at higher DO. A threshold DO is required to satisfy biological activity and reduce the growth of undesirable organisms. Above this threshold DO the process performance increases insignificantly, if at all. A DO of 2.0 mg/l is typically used as the target concentration, but field experience indicates that consistently maintaining DO between 1.0 and 2.0 mg/l will improve energy efficiency without affecting the biological process.

The type of process also influences energy consumption, although this is often dictated by effluent requirements. Conventional BOD removal with low MCRT (mean cell retention time) or sludge age has the lowest efficiency. Long MCRT with nitrification has higher efficiency. Long MCRT combined with nitrification and denitrification has the best energy efficiency.

Blowers

Diffusers and process operation dictate the amount of air required at the aeration basins. The operation of blowers providing air to diffusers is equally important in minimizing system energy. Blower mechanical design establishes the basic efficiency, but operating considerations greatly influence actual power requirements.

Small systems usually employ positive displacement (PD) blowers. With PD blowers the airflow rate must be controlled by varying the blower speed, most commonly with variable frequency drives (VFDs). Large systems use single stage centrifugal (turbo) blowers. Inlet guide vanes, variable discharge diffuser vanes, or a combination of both types of vanes, usually control the airflow rate.

The airflow supplied by the blowers must be matched to the actual process requirements. Reducing the airflow rate required by the process is not advantageous if blower flow cannot be reduced too. Blower airflow should be adjusted continuously by automatic control or frequently by manual adjustment.

The need to reduce airflow implies that adequate turndown (the ratio of minimum air flow rate to maximum air flow rate) is available. This is often neglected in system design, where the primary concern is necessarily providing adequate capacity to meet worst-case demand. Most facilities operate at much lower process airflow than worst case conditions dictate. Diurnal variations in hydraulic and organic loading result in fluctuating demands throughout the day. It is desirable to provide more blowers of lower capacity rather than a few large blowers, even if the larger units are more efficient. In existing facilities, if the blowers do not have adequate turndown to meet the minimum process airflow rate, it may be cost effective to install additional or replacement blowers that are more closely matched to the actual operating range.

Minimizing pressure ratio is also important to optimizing blower power consumption. At a given air

Aerator Type	SAE **lbO2/hp-h** **(kgO2/kW-h)**	Low SRT AE at 2 mg/L DO	High SRT AE At 2 mg/L DO
High Speed	1.5–2.2 (0.9–1.3)	0.7–1.4 (0.4-0.8)	
Low Speed	2.5–3.5 (1.5–2.1)	1.2-2.5 (0.7–1.5)	
Turbine	2-3 (1.2-1.8)	0.6-0.9 (0.4-0.6)	0.9-1.4 (0.6-0.8)
Coarse Bubble	1-2.5 (0.6 –1.5)	0.5 – 1.2 (0.3-0.7)	0.6–1.6 (0.4-0.9)
Fine Pore	6–8 (3.6–4.8)	1.2-1.6 (0.7–1.0)	3.3-4.4 (2–2.6)

Table 1. These approximations should be used only as guidelines. Transfer efficiency will depend on site-specific conditions.

Blowers such as the Ram X blower (above) provide air to the diffusers, an operation that is important to consider in optimizing the system energy use. *Photo by Dresser Roots* flow rate, higher discharge pressure increases the power requirement. The discharge pressure can be minimized by adequately sizing air distribution piping and by properly adjusting the airflow control valves at the aeration basins and diffuser grid drop legs. At least one flow control valve should always be at the maximum open position, with other valves adjusted as required to insure proper distribution proportional to demand. In automated systems a Most-Open-Valve (MOV) strategy should be employed to reduce power consumption.

High inlet pressure drop through filters and piping also increases blower power consumption. Filters should be adequately sized and excessive filtration should be avoided. Experience has shown that removal of 95% of particles 10 micron or larger is typically sufficient to both protect blowers and prevent diffuser airside fouling. Filters should be maintained regularly to minimize pressure drop.

Automation

Automatic control of the aeration system is a valuable tool in minimizing energy because it is very difficult to manually monitor the process and make the required adjustments at the necessary frequency. The airflow rate required to meet process demand in most wastewater treatment plants constantly changes due to diurnal and seasonal fluctuations, variations in organic loading from plant influent and internal side streams, and changing process performance.

Automatic control systems are valuable tools to minimize energy use in aeration basins. This photo shows a multistage compressor on a trailer. ***Photo by Dresser Roots***

The development of a control strategy must include the same factors as system design and maintenance. The control of the aeration basins must minimize airflow demand. The control of the aeration blowers must maximize the efficiency of providing airflow required by the process.

The most common control technique for aeration basins is DO control. A transmitter is used to continuously monitor the aeration basins. If the DO is above the operator's target (set point) then the airflow to the basins is reduced. This effectively increases OTE by reducing the flow rate per diffuser. To maintain proper performance of the biological treatment system it is correspondingly necessary to increase the air flow when the DO level drops. Increasing the mass flow rate of oxygen delivered to the basin offsets OTE reduction.

Proper selection of DO set point is important. If the control system performs properly it is not necessary to set the DO above actual process requirement to accommodate diurnal variations or sudden load increases. Since OTE drops severely as DO concentration increases, the target DO must be set to the minimum level needed for treatment.

In smaller treatment plants or facilities with one aeration basin per blower, the demand and DO at the aeration basins can be used to directly control blower airflow rate. In larger systems it is cost effective to provide automatic control of airflow to individual aeration basins. A 5% energy reduction can be typically achieved by consistently maintaining each basin DO. MOV logic should be included in these systems to minimize blower discharge pressure.

Whether or not airflow control of individual basins is provided the blower output must be decreased or increased to match the process demand. Constant pressure control was used in older systems to force blower airflow changes. Many newer systems interact with the basin MOV logic to change the pressure set point as basin valves modulate. Other systems eliminate the pressure control entirely and coordinate basin demand and blower supply with direct flow control logic.

Minimizing aeration energy is important for reducing resource consumption and for minimizing operating expense. Although the development of an energy conservation process can be complex, its many variables facilitate a multitude of cost-saving solutions that can bring about dramatic savings in energy consumption and cost.

Authors' Note

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