A DIGITAL CONTROL SYSTEM FOR OPTIMAL OXYGEN TRANSFER EFFICIENCY

Arnold Schwarzenegger
Governor

APPENDIX B: TECHNOLOGY ASSESSMENT REPORT

PIER FINAL PROJECT REPORT

Prepared For:

California Energy Commission
Public Interest Energy Research Program

Prepared By:
Southern California Edison
University of California, Los Angeles
Utility Technology Associates

January 2010
CEC-500-2009-076-APB

Prepared By:
Southern California Edison
Lory Larson
Los Angeles, California 95616

Prepared For:
Public Interest Energy Research (PIER) Program
California Energy Commission

Paul Roggensack
Contract Manager

Michael Lozano
Program Area Lead
Industrial/Agricultural/Water End-Use Energy Efficiency

Virginia Lew
Office Manager
Energy Efficiency Research Office

Thom Kelly, Ph.D.
Deputy Director
ENERGY RESEARCH & DEVELOPMENT DIVISION

Melissa Jones
Executive Director

TECHNICAL ASSESSMENT
OF
THE OFF-GAS TECHNOLOGY
FOR
AERATION PERFORMANCE MONITORING

Submitted to:
Southern California Edison

Customer Service Department
Design & Engineering Services Group
6042B N. Irwindale Avenue
Irwindale, CA 91702

Prepared by:
Utility Technology Associates
14988 El Soneto Drive
Whittier, CA 90605

June 2006

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1.0
EXECUTIVE SUMMARY

Over 60 percent of all wastewater treatment plants in the U.S. use the activated sludge process as secondary treatment system. About 50 to 85 percent of the total energy consumed in a biological wastewater treatment plant is in aeration. The activated sludge process, the most common process, is performed in large aeration basins to provide air for microorganisms, through biodegradation, to remove nutrients and pollutants.

One of the wastewater industry's major challenges is the monitoring of how well the secondary treatment process performs in breaking down waste. There are several ways to monitor this secondary treatment process. The most informative method is to calculate the oxygen transfer efficiency (OTE) using data collected by an instrument that measures oxygen in the off-gas emitted from the basin. The OTE data is also used to determine when the basin's diffuser system requires cleaning, repair, or replacement. Currently, the commercially available OTE instruments including the off-gas monitoring equipment are large, heavy, and fragile, requiring a crew of four to six to operate. In addition, other tests are needed to measure factors for the conversion of OTE to standard conditions. These measurements are time, labor, and equipment intensive and require special staff expertise. The only option for obtaining this OTE data is to outsource the tests to expensive consultants rather than doing it in-house. Because of the expense and difficulty of OTE measurements, most wastewater treatment plants rarely take them.

Project Objectives and Tasks Performed

This overall project has the objective of designing and demonstrating a new portable, fully-automated OTE monitoring technology for the purpose of evaluating and optimizing oxygen uptake, thereby reducing energy demand. In addition, the project will develop practical tools for the wastewater industry to facilitate the routine "in-house" monitoring of wastewater performance and with the intent to reduce energy use, improve operating efficiency, and conserve energy by 25 to 40% at treatment plants throughout California. Technology Assessment is one of the seven tasks proposed for this study. The main objective of the technology assessment task is to perform an independent assessment of the off-gas technology, and provide an objective critique of the usefulness of the technology for the wastewater industry. This report is not written as a technical publication for the scientific community. The general audiences are not considered wastewater treatment savvy. It is assumed that they know little about wastewater aeration. For those reasons, the report provides an introduction to the importance of aeration and the type of aeration systems in wastewater treatment to make the reading easier to understand and follow. Specific tasks performed in this report include:

- Introduction to wastewater aeration
- Concern of aeration to energy consumption
- Overview of the aeration processes
- Technologies for aeration control/monitoring
- Analysis of the off-gas technology
- Summary conclusions and recommendations

Aeration Technology Overview
Aeration is the heart of an activated sludge process in wastewater treatment. Since energy use in aeration contributes over 50% of total usage, it is important to understand the principles and processes governing sludge aeration as well as the types of processes, methods of aeration, types of diffusers, factors influencing oxygen transfer efficiency and the importance of aeration maintenance and cleaning.

Problem Statement
To minimize potential aeration problems which ultimately lead to excessive energy use, it is important to address both operational and monitoring concerns. Operational concerns relate primarily to diffuser fouling which is a function of cleaning and maintenance frequency of nozzles. Monitoring concerns relate to accuracy and ease of monitoring to optimize performance with least aeration energy. Current monitoring technologies are either too bulky, difficult to perform, costly, and/or labor intensive.

Technologies Available for Aeration Control/Monitoring
Several technologies were found to be applicable to aeration monitoring. Traditional practices were to measure pH and DO of the wastewater, sometimes complemented with BOD/COD grab sample analyses. More recent measurements use DO probes which are fuel cells with a semi-permeable membrane placed ahead of the electrode. With this method, one cannot determine the operating efficiency nor calculate energy consumption or requirements. In addition, the readings drift frequently making them unreliable and/or inaccurate. The more recent online DO monitoring technologies include oxidation reduction potential (ORP), respirometer, inert gas tracer, non-steady state H_2O_2 method, and off-gas technologies. All these technologies have been used with some degree of success. Advantages and limitations of these technologies are discussed and analyzed.

Potential Benefits of the Off-gas Technology
The intent of this project is to develop a simple and low cost monitoring system for the off-gas technology to be used at all wastewater treatment plants that have activated sludge treatment processes. Proper and frequent monitoring of the off-gas from aeration will provide accurate information on treatment performance and mitigate occurrences for over-aeration. By so doing, significant energy savings can be derived. It is estimated, within the SCE service territory, a maximum potential of energy savings in the amount of 71.18 million kWh annually is achievable.

Summary Conclusions and Recommendations
This report reviewed several monitoring technologies for DO and oxygen transfer efficiency measurement. It was concluded that the off-gas technology, as currently evaluated by the UCLA researchers, is an excellent monitoring technology, well suited for evaluating process water performance. Because of its current bulky configuration and weight constraints as well as the costs associated with procuring and performing the actual monitoring, the technology is not commonly used by wastewater treatment plant operators. It is recommended that UCLA's on-going research for reducing size, weight, and costs of the off-gas equipment be continued, leading to commercial deployment. In addition, two additional research areas for improving aeration performance also need to be addressed. They are: blower control and SRT/DO optimization.

2.0
BACKGROUND

The wastewater treatment industry is one of the most energy intensive industries in California, consuming over 3 percent of the state's total energy. Recently, the industry is faced with serious problems of excessive energy usage including high energy costs, supply shortage, and inefficient/outdated monitoring equipment. The wastewater industry in California wastes millions of dollars in energy costs each year from excessive aeration.

2.1 What is Wastewater Aeration?

Wastewater aeration is the process aimed at injecting air into the wastewater to promote aerobic biodegradation of waste material. It is an integral part of most biological wastewater treatment systems. Unlike chemical treatment which uses chemicals to react and stabilize solids in the waste stream, biological treatment uses microorganisms that occur naturally in wastewater to degrade and stabilize wastewater contaminants. In municipal wastewater treatment, aeration is part of the secondary treatment process, preceded usually by pretreatment using grid chambers for large objects and grit removal and primary treatment with sedimentation basins for suspended solids removal. The most common processes where aeration is employed are the activated sludge process, trickling filters, and aerated lagoons.

Activated sludge process is the most common option in secondary treatment. It is based on aerating a biological tank, which promotes microbial growth in the wastewater. The microbes feed on the organic material, form aggregated flocs, which then can easily settle out. Afters settling in a separate settling tank, bacteria forming the "activated sludge" are continually recirculated back to the aeration basin to increase the rate of organic decomposition. Microorganisms adsorb dissolved and suspended matter, thus converting nonsettleable solids into settleable solids. This usually corresponds to approximately 85% removal of the biological oxygen demand (BOD) and total suspended solids (TSS) in the wastewater.

2.2 Why is Aeration Important to Wastewater Treatment?

Aeration is the most critical component of treatment system using activated sludge process. A well designed aeration system has a direct impact on the level of wastewater treatment it achieves. An ample and evenly distributed oxygen supply system in an aeration basin is the key to rapid, economically-viable, and effective wastewater treatment.

2.3 How does Aeration Work?

Aeration provides oxygen to bacteria for treating and stabilizing the wastewater. Oxygen is needed by the bacteria to allow biodegradation reactions to proceed. The supplied oxygen is utilized by bacteria in the wastewater to break down the organic matter containing carbon to form carbon dioxide and water. Without the presence of sufficient oxygen, bacteria are not able to biodegrade the incoming organic matter in a reasonable time. In the absence of dissolved oxygen, degradation must occur under septic conditions which are slow, odorous, and yield incomplete conversions of pollutants. Under septic conditions, some of the carbon will react with hydrogen and sulfur to form hydrogen sulfide and methane. Other carbon will be converted to organic acids that create low pH conditions in the basin and make the water more difficult to treat and promote odor formation. Biodegradation of organic matter in the absence of oxygen is a very slow biological process.

2.4 What are the Energy Implications of Aeration?

Activated sludge aeration systems consume 50-90% of the energy used at most wastewater treatment plants, according to a recent survey by the U.S. EPA. A significant component of operation and maintenance costs, aeration systems have an equal effect on plant performance and capacity. A typical size 10 MGD activated sludge wastewater plant uses approximately 2,500 kWh/MG of electricity (CEC published data). Assume an average of 65 percent of the plant energy use is related to aeration, this equates to1,625 kWh/MG; or for a 10 MGD plant, this would correspond to 5.9 million kWh/year for aeration alone. Improper aeration can easily increase energy usage by as much as 50 percent.

3.0
PROBLEM STATEMENT

Over 60 percent of all wastewater treatment plants in the U.S. use the activated sludge process as their secondary treatment system. As discussed in Section 2.4 of this report, at least 50 percent of the energy consumed in a wastewater treatment plant is in aeration. The activated sludge process is performed in large aeration basins and provides air for the microorganisms to remove nutrients and pollutants through biodegradation. The development of fine-pore diffuser (small bubble) aeration made the operating costs of these plants much lower than they were with earlier coarse-bubble (large bubble) aeration. Unfortunately, porous ceramic disk and dome diffusers, and to a lesser extent, membrane diffusers, used in most fine-pore systems, are highly vulnerable to fouling by bacterial-slime growth and hard-water scale deposition. Cessation of airflow through the diffuser, due to either a power failure or intentional system shutoff, allows water pressure at the bottom of the tank to drive foulants onto the surface of the diffusers. This greatly reduces oxygen transfer efficiency (OTE) in a few minutes. Fouling of diffusers reduces OTE and significantly increases the amount of air, and hence energy and cost, needed to run the process.

3.1 Operation Concern - Diffuser Fouling

There are three main reasons for selecting fine-pore diffusers: a) the OTE of fine-pore systems is typically twice as high as when coarse bubbles are used; b) air flowrate, and hence energy consumption for aeration, is inversely proportional to OTE, because the amount of oxygen actually transferred must at least be equal to the oxygen consumed by the process; c) the power used by the blowers for the aeration tanks ranges from 50% to 80% of the total energy consumption of an activated sludge plant. Most of this energy is consumed by the process's blower system in the aeration process. This pumped-in air contains the oxygen that microorganisms need to breakdown waste in the water. Diffuser fouling for fine-pore aeration is the most significant operational concern in wastewater aeration. When the fine-pore diffusers are fouled, their efficiency is reduced to the same levels of plants that use coarse-pore diffusers. Diffuser fouling diminishes potential energy savings derived by switching from older aeration coarse bubble to fine-pore diffusers.

3.2 Monitoring Concerns

In addition to diffuser fouling, the other major energy-wasting concern is the monitoring of how well the secondary treatment process performs in breaking down the waste. There are several ways to monitor this secondary treatment process. One informative method is to calculate OTE using data collected by the off-gas technology, an instrument that measures oxygen in the gas emitted from the basin. The OTE data is used to determine when the basin's diffuser system requires cleaning, repair, or replacement. At present, the commercially available off-gas instruments are large, heavy, and fragile, requiring a crew of four to six to operate. In addition, other experiments are needed to measure factors for the conversion of OTE to standard conditions. These measurements are time, labor, and equipment intensive and require special staff expertise. Currently, the only option to obtain this OTE data is to outsource the tests to expensive consultants rather than monitoring by treatment plant staff in-house. Because of the expense and difficulty of OTE measurements, most plants rarely take them. Without this vital information, the wastewater industry is unable to determine when efficiencies have dropped to a level where it becomes cost-effective to clean, repair, or replace the diffuser systems. For example, at the City of Los Angeles's Terminal Island Treatment Plant (TITP), dirty diffusers can cause an efficiency drop of over 50%, corresponding to at least $197,100/yr wasted, essentially due to the limitations of present day off-gas testing equipment.

A further problem with secondary wastewater treatment is that plants lack the information necessary to optimize aeration in response to process change conditions. The basic theory is that, in activated sludge systems, when air flux decreases OTE increases. This is the key relationship in aeration control because it determines the change of airflow needed to respond to a change in oxygen demand. *Qualitatively*, this relationship is understood: increasing air fluxes increase the average diameters of bubbles, thereby reducing the surface/volume ratio and increasing the speed of the bubbles, both of which work against oxygen transfer. However, a thorough *quantitative* description of this relationship under changing process conditions has yet to be given, mainly because of the lack of a user-friendly device for measuring OTE.

4.0
TECHNOLOGY ASSESSMENT OBJECTIVES

This is a planned research program intended to benefit the wastewater treatment industry in California, and ultimately the nation with the overall objective of designing and demonstrating a new portable, fully-automated off-gas technology for the purpose of evaluating and optimizing oxygen uptake, thereby reducing energy demand. In addition this project will also provide practical tools for the wastewater industry to reduce energy use, improve operating efficiency, reduce time, labor, and cost for OTE monitoring, and conserve energy by 25 to 40% at treatment plants throughout California. Technology Assessment is one of the seven tasks proposed for this study. This task presents the following information:

- Introduction to wastewater aeration
- Concern of wastewater aeration and energy consumption
- Overview of the aeration processes
- Technologies for aeration control/monitoring
- Analysis of the off-gas technology
- Summary conclusions and recommendations

5.0
AERATION TECHNOLOGY OVERVIEW

Aeration is the heart of an activated sludge process in wastewater treatment. According to the U.S. Environmental Protection Agency, activated sludge aeration systems consume 50 to 80 percent of the energy used at most wastewater treatment plants. It is important, therefore, to understand the fundamental principles governing activated sludge aeration as well as the types of aeration processes, methods of maintenance, and aeration control/monitoring required.

5.1 Description of an Activated Sludge System

In an activated sludge system, wastewater is aerated in a tank (reactor) where bacteria are encouraged to grow with a supply of: oxygen (air), food (biological oxygen demand, BOD), proper temperature, and adequate contact time. As bacteria consume BOD, they grow and multiply. After sufficient contact time, treated wastewater flows into secondary clarifiers (sedimentation basins) where bacterial cells settle and are removed from clarifiers as sludge. Part of the sludge is recycled back to the activated sludge tank to maintain bacteria population. The remainder sludge is wasted. Flow characteristics of the two most commonly used reactor types are the complete mix or continuous flow stirred-tank reactor (CSTR) and the plug flow reactor (PFR). In CSTR operation, complete mixing occurs when particles entering the tank are completely dispersed throughout the tank. In plug flow, fluid particles pass through the tank and are discharged in the same sequence in which they enter. In PFR operation, fluid particles pass through the tank and are discharged in the same sequence in which they enter. The particles retain their identity and remain in the tank for a time equal to the theoretical detention time. Longitudinal dispersion is absent in the PFR operation.

5.2 Types of Activated Sludge (A/S) Processes

The activated sludge process is very flexible and can be adapted to a variety of treatment schemes depending on the type of biological wastes requiring treatment. In general, the following six types of A/S processes are most commonly encountered: conventional, complete-mix, step-feed, modified-aeration, contact-stabilization, and extended-aeration.

5.2.1 Conventional

The conventional A/S process consists of an aeration tank, a secondary clarifier, and a sludge recycle line. Sludge wasting is accomplished from the recycled or mixed liquor line. Both influent settled sewage and recycled sludge enter the tank at the head end and are aerated for a period of about 6 hours. During this period, adsorption, flocculation, and oxidation of organic matter take place. The mixed liquor is settled in the clarifier, and sludge is returned at a rate of 25 to 50% of influent flowrate.

5.2.2 Complete-Mix

The complete-mix process represents the hydraulic regime of a mechanically stirred reactor. The influent settled sewage and return sludge flow are introduced at several points in the aeration tank from the central channel. The mixed liquor is aerated as it passes from the central channel to effluent channels at both sides of the aeration tank. The aeration tank effluent is collected and settled in the A/S clarifier.

5.2.3. Step-Feed

The step-feed or step aeration process is a modification of the A/S process in which the settled sewage is introduced at several points in the aeration tank to equalize the organic loading and reduce peak oxygen demand. The aeration tank is subdivided into four or more parallel channels through the use of baffles. Each channel comprises a separate step, and the several steps are linked together in series. Return activated sludge enters the first step of the aeration tank along with a portion of the settled sewage. The multiple-point introduction of feed maintains an activated sludge with high absorptive properties, so that the soluble organics are removed within a relatively short contact period. Higher BOD loadings are therefore possible per 1,000 cu ft of aeration-tank volume.

5.2.4 Modified-Aeration

The flow diagram for the modified-aeration process is identical with that of the conventional or tapered-aeration process. The modified-aeration process, however, uses shorter aeration times, usually 1.5 to 3 hr, and a high food to micoroorganism (F/M) ratio. BOD removal is only in the 60 to 75% range and is, therefore, not suitable where high-quality effluent is desired.

5.2.5 Contact-Stabilization

Contact stabilization differs from the above processes in that an additional basin/tank or stabilization basin is provided for the return sludge from the clarifier to further breakdown the residual BOD from the contact basin. In this process, BOD removal is postulated to take place in two stages. The first is the absorptive phase which requires 20 to 40 min. During this phase most of the colloidal, finely suspended, and dissolved organics are absorbed in the activated sludge. The second phase, oxidation, then continues, and the absorbed organics are metabolically assimilated. The settled sewage is mixed with return activated sludge and aerated in a contact tank for 30 to 90 min. During this period, the absorbed organics are utilized for energy and production of new cells. A portion of the return sludge is wasted prior to recycle, to maintain a constant MLVSS (mixed liquor volatile suspended solid) concentration in the tank. The Kraus Process is a variation of this process in which the anaerobically digested sludge and digester supernatant are added to the return sludge to improve the settling of the floc.

5.2.6 Extended-Aeration

The extended-aeration process operates in the endogenous respiration phase of the growth curve, which necessitates a relatively low organic loading and long aeration time. It is generally applied to small treatment plants of less than 1 mgd capacity. This process is used extensively for prefabricated package plants that provide treatment for housing subdivisions, isolated institutions, small communities, schools, etc. Aerobic digestion of the excess solids, followed by dewatering on open sand beds, usually follows separate sludge wasting. Primary sedimentation is omitted from the process to simplify the sludge treatment and disposal. Oxidation ditch is a variation of this process.

A typical range of design parameters for the various activated sludge processes discussed above is shown in Table 5.1.

TABLE 5.1 TYPICAL DESIGN PARAMETERS FOR ACTIVATED SLUDGE PROCESSES

Process	*Θ_c (d)*	*Θ (h)*	*F/M*	*Qr/Q*	*X (mg/L)*
Conventional	5 - 15	4 - 8	0.2 - 0.4	0.25 - 5	1,500 – 3,000
Complete-mix	5 – 15	3 – 5	0.2 – 0.6	0.25 – 1	3,000 – 6,000
Step-aeration	5 – 15	3 – 5	0.2 – 0.4	0.25 – 0.75	2,000 – 3,500
Modified-aeration	0.2 – 0.5	1.5 - 3	1.5 – 5.0	0.05 – 0.15	200 – 500
Contact-stabilization	5 – 15	0.5 – 1 3 - 6	0.2 – 0.6	0.25 – 1	1,000 – 3,000 4,000 – 6,000
Extended-aeration	20 - 30	18 - 36	0.05 - 0.15	0.75 – 1.5	3,000 – 6,000

Legend:
- Θ_c mean cell retention time or solids retention time (SRT) in days
- Θ_h hydraulic retention time in hours (V/Q)
- F/M food to microorganism ratio (lbs BOD/lb of MLVSS-day)
- *Qr/Q* sludge recirculation ratio
- *X* *mixed liquor volatile suspended solids concentration (MLVSS in mg/L)*

5.3 Methods of Aeration

The equipment used to deliver oxygen to the aeration system is typically provided by surface mechanical type aerators or subsurface diffused aeration systems. Some common types of mechanical surface aeration equipment include low speed mechanical blade aerators, direct drive surface propeller aerators, and brush type surface aerators. Subsurface diffused aeration systems include a low pressure, high volume air compressor (blower), air piping system, and diffusers that break the air into bubbles as they are dispersed through the aeration tank. The most commonly used blowers are positive displacement type blowers and centrifugal blowers (single and multi-stage).

The diffusion of air can be accomplished with several types of diffusers. Typical clean water oxygen transfer rates are shown in Table 5.2.

TABLE 5.2 TYPICAL CLEAN WATER OXYGEN TRANSFER RATES (EPA 1984)

Diffuser Type and Placement	**Oxygen Transfer Rate Lb O_2/hp-hr**
Coarse Bubble Diffusers	2.0
Fine Bubble Diffusers	6.5
Surface Mechanical Aerators	3.0
Submerged Turbine Aerators	2.0
Jet Aerators	2.8

To more accurately compare aeration system equipment, the relative rate of oxygen transfer (alpha value) in wastewater compared to clean water must be established. Typical alphas (α) are shown in Table 5.3.

TABLE 5.3 TYPICAL ALPHA (α) VALUES

Aeration System	Typical Alpha (α)
Coarse Bubble Diffusers	0.8
Fine Bubble Diffusers	0.4-0.8
Jet Aeration	0.75
Surface Mechanical Aerators	0.8-1.0
Submerged Turbines	0.85

The value for oxygen saturation in wastewater compared to clean water is known as the beta value (β). For municipal wastewater, 0.95 to 1.0 is typically used (EPA 1989).

Another important function of the aeration equipment is to provide adequate mixing in the tanks to prevent solids from settling. This is an important aspect which is often overlooked when aeration systems are evaluated for energy saving opportunities. Table 5.4 shows typical minimum mixing values for aeration tanks (EPA 1989).

TABLE 5.4 TYPICAL AERATION TANK MIXING REQUIREMENTS

Type of Aeration System	Mixing Requirements
Coarse Bubble Diffusers	20 to 30 scfm/1000 cu.ft.
Fine Bubble Diffusers	7 to 10 scfm/1000 cu.ft.
Mechanical Surface Aeration	0.6 to1.15 hp/1000 cu.ft.

5.4 Types of Fine Bubble Diffusers for Subsurface Aeration

In a subsurface system, air is introduced by diffusers or other devices submerged in the wastewater. Fine pore diffusion is a subsurface form of aeration in which air is introduced in very small bubbles. There are 5 basic types of diffusers: discs, tubes, domes, panels, and plates. These diffusers can be made from a variety of materials including ceramics, plastics, or flexible perforated membranes. Ceramic diffusers have been manufactured in dome, plate, tube and disc shapes, however the most commonly marketed version today is the disc. The discs are typically 9” (3.54 cm) in diameter, although they are made in sizes from 7” (2.76 cm) to 20” (7.87 cm) diameter. The thickness of the media is from 0.75” to 7.5”. Membranes are available in various materials and thicknesses, from to 0.0197” to 0.0315” (0.5-0.8 mm). Membrane materials include Ethylene Propylene Dimer (EPDM) which is the most common type, as well as Urethane and Silicone. The main ingredient in an EPDM membrane, which is the most commonly used type, is EPDM; however, natural rubber, carbon black, ash, organic additives, peroxides and plasticizers are also used in varying proportions.

Disc Diffusers: These are relatively flat and range from 7" to 9.4" (18 to 24 cm) in diameter with thicknesses of 0.5" to 0.75" (13 to 19 mm). Materials for discs include ceramics, porous plastics, and perforated membranes. The disc is mounted on a plastic saddle-type base plate, and either a center bolt or a peripheral clamping ring is used to secure the media and the holder together. Airflow is typically in the range of 0.25 to 1.5 liters/second per diffuser.

Tube/Flexible Sheath Diffusers: A typical tube diffuser is either a rigid ceramic or plastic hollow cylinder (tube) or a flexible membrane secured by end plates in the shape of a tube. A tube diffuser has a media portion up to 200 cm long and the outside diameter is approximately 6.4 to 7.6 cm. Tube diffusers are made of either stainless steel or durable plastic. Threaded rods are used with ceramic or plastic. Air flows through the tube diffusers in the range of 1 to 5 liters/second.

Dome Diffusers: Dome diffusers are made from ceramics or porous plastics. Dome diffusers are typically circular, 18 cm in diameter and 3.8 cm high. The media is about 15 mm thick on the edges and 19 mm on the flat surface. The dome diffuser is mounted on either a polyvinyl chloride or a steel saddle-type base plate. The airflow rate for dome diffusers is 0.25 to 1.0 L/s with a typical value of 0.5 L/s.

Panels: These types of diffusers consist of a flat box of custom size with a large sheet of punched polymeric membrane, such as the membrane used for tubes, closing the top of the box. Air is distributed inside the box and released from the top membranes. In general, these diffusers have an air flowrate of the same range of tubes, on a L/m^2 basis. Typically, higher tank floor coverage is reached when employing panels over smaller fine-pore diffuser models.

Plate Diffusers: Plate diffusers, made usually from ceramic material, are flat and rectangular, approximately 30 cm^2 in area, and 2.5 to 3.8 cm thick. Installation involves either grouting the plates into recesses in the floor, cementing them into prefabricated holders, or clamping them into metal holders. Air plenums run under the plates and supply air from headers. In new installations, plate diffusers have largely been replaced by porous discs, domes and tubes.

5.5 Factors that Influence Oxygen Transfer Efficiency

There are numerous parameters in wastewater treatment that can impact the rate and efficiency of oxygen transfer. A number of these are either inherent in the physical plant design (dimension of reactor, retention time, hydraulic flow rate, etc.) or intrinsic to the wastewater (salinity, pH, temperature, hardness, etc.) and are beyond the plant operator's control. What we are discussing below are a few notable facts that are known to influence the oxygen transfer efficiency.

5.5.1 Bubble Size

Bubble size affects the oxygen transfer efficiency. Smaller bubbles have more surface area per unit volume. This provides more area through which oxygen can diffuse and thereby increases overall transfer efficiency. Since fine bubbles provide larger total surface area, they create more friction and rise slower than coarse bubbles. The combination of more transfer area and a greater contact time enhances transfer efficiency. By inference, therefore, replacement of coarse bubble diffusers with fine bubble diffusers can greatly enhance oxygen transfer efficiency and simultaneously reduce significant amount of energy for aeration.

5.5.2 Surface Active Agents
Surface active agents (surfactants), such as detergents, lower alpha and the oxygen transfer efficiency. The thin film of detergent molecules between the air bubble and the wastewater can act as a barrier, increasing resistance to oxygen transfer. Pretreatment may be required to remove high concentrations of surfactants with either chemicals such as ozone, activated carbon, organophillic clay or bentonite clay powder prior to aeration.

5.5.3. Fouling
Fouling decreases transfer efficiency. Most fine bubble systems being installed today use a diffuser made of a flexible synthetic membrane with many small slits or a ceramic disk with very fine holes. Both provide attractive sites for microbial growth and precipitation of inorganic compounds. This type of fouling can cause bubbles to coalesce, thereby decreasing the overall oxygen transfer efficiency. Prechlorination or ozonation may reduce the frequency of fouling and greatly improve oxygen transfer efficiency.

5.5.4 Aeration Basin and Aerator Layout
Aeration basin and aerator layout geometry can dramatically alter oxygen transfer efficiency. Standard clean water transfer efficiency tests are usually based on full floor aerator coverage. A turbulent counter-current flow regime is established with a volume of water being dragged upward with the rising bubbles, being opposed by an equal flow of water traveling downward. In large basins, full floor coverage is not normally needed to meet the biological aeration demands. As a result of incomplete coverage, large scale currents can form a spiral roll in the basins. The air bubbles flow with the water, which significantly reduces the transfer efficiency. Compared with the full floor configuration, many more air bubbles short-circuit their way to the top of the aeration basin.

5.6 Process Design Considerations
Factors that must be considered in the design of the activated-sludge process include: 1) loading criteria, 2) selection of reactor type, 3) sludge production, 4) oxygen requirements and transfer, 5) nutrient requirements, 6) environmental requirements, 7) solid liquid separation, and 8) effluent characteristics. The following is an overview and discussion of these parameters. Detailed discussion can be found in any wastewater design text book such as Metcalf and Eddy's Wastewater Engineering text book, 2003.

5.6.1 Loading Criteria
The two most accepted and commonly used parameters for design and control of activated sludge systems are: food to microorganism (F/M) ratio and mean cell retention

time Θ_c. Typical values for F/M ratio are from 0.2 to 0.5 with the lower value representing conservative operation. Mean cell retention time are typically in the range of 4 to 8 days. The relationship between F/M ratio and Θ_c is: $1/\Theta_c = YU - k_d$

Where Y = growth yield coefficient, mass of microorg. /mass of substrate utilized
U = F/M ratio
k_d = microorganism decay ratio

5.6.2 Selection of Reactor Type

Reactor types have been discussed at length in Section 5.2. The selection of activated sludge process is a function of many parameters including reaction kinetics, oxygen transfer requirements, nature of the wastewater to be treated and local environmental conditions. The actual selection process would require research beyond what can be discussed here and hence will not be elaborated further.

5.6.3 Sludge Production

The quantity of sludge produced per day needs to be established, as it will affect the design of the sludge handling and disposal facilities. Both the average and maximum rates of sludge production must be compiled to determine the expected quantities of solids entering the treatment facility. In the absence of actual data, one can obtain arbitrary quantities of sludge production based on subjective engineering assumptions.

5.6.4 Oxygen Requirements and Transfer

The amount of oxygen or air required is a function of the BOD of the waste and the amount of sludge wastage from the system per day. Typically the air supplied should be sufficient to maintain a minimum dissolved oxygen concentration throughout the aeration tank of 1 to 2 mg/liter. For diffused-air aeration, the amount of air used commonly ranged from 0.5 to 2.0 cu ft/gal with 1.0 cu ft/gal as a design factor.

5.6.5 Nutrient Requirement

Nutrients (primarily nitrogen and phosphate) are required to insure a healthy biological system for proper waste degradation and treatment. Typical amount of nitrogen required is 12.4 percent of the cells (MLVSS) produced per day by weight and the phosphate requirement is one-fifth of the nitrogen amount.

5.6.6 Environmental Requirement

The most important parameters are pH and temperature because both have significant impacts on the performance of the treatment process. The pH is important for growth of microorganisms. Most organisms cannot tolerate pH levels above 9.5 or below 4.0. The optimum pH for growth lies between 6.5 and 7.5. Temperature not only influences the metabolic activities of the microbiological population, but also has a profound effect on such factors as gas transfer rates and the settling characteristics of the biological solids.

5.6.7 Solid-Liquid Separation

Solid-liquid separation is the most important aspect of biological waste treatment since performance and efficiency of treatment is tied to the clarity and low BOD effluent which cannot occur without a good separation system. A well designed clarifier or sedimentation basin must consider the following factors: type of tanks, surface loading rate, solids loading rate, flow-through velocity, weir placement and loading, and scum removal.

5.6.8 Effluent Characteristics

A well operating biological activated sludge plant should produce an effluent that is clear, low in suspended solids, and low in soluble BOD. Typical values for effluent should have total suspended solids of equal or less than 30 mg/liter and BOD of 2 to 10 mg/liter

5.7 Aeration System Maintenance and Cleaning

Both membranes and ceramics foul over time, however ceramics foul more quickly. New ceramic diffuser media have lower headloss than most new EPDM membrane media, however membrane headloss can be controlled by orifice size and spacing. Membrane media is less expensive to produce than ceramic media, and also provides a lifetime of lower operating costs as a benefit of its reduced fouling rate. Membrane diffusers have performed better in high loading and on/off cycling treatment plants. They are subject to much less fouling than ceramics under most circumstances when membrane material is properly chosen.

Routine Maintenance:

Diffusers should be checked when the activated sludge tank is out of service and/or empty. Formic acid is frequently used with success against carbonating. To keep the pores open, formic acid is sprayed into the compressed air for a short time. Also, regular use with maximum air flow for a short time reduces fouling potential and helps keep the diffuser in good condition for a long time.

Ceramic Cleaning System:

In-situ gas cleaning systems are commonly sold together with ceramic diffuser systems. The Sanitaire in-situ gas cleaning system for ceramic fine bubble aeration is a notable example. The cleaning agent most commonly used is muriatic acid, containing 10 to 14% HCl which is applied for periods of 30 minutes to a grid of ceramic diffusers in-situ. The airflow rates are raised to maximum to physically assist the acid in removing foulants. Other methods used include a 5 % bleach solution and formic acid.

Membrane Cleaning System:

Ethylene Propylene Diene Monomer (EPDM) is the most common material used for the membrane diffusers. Other materials used include natural rubber, carbon black, ash, organic additives, peroxides and plasticizers. Membranes tend to not foul as readily as the ceramics. Some newer membranes have built-in fouling-retardant features. Cleaning is usually performed in-situ for most newer designs although both in-situ and ex-situ have been practiced. Tank-top hosing with high pressure water effluent is typically practiced, although anhydrous HCl gas has also been used for in-situ application.

6.0
TECHNOLOGIES AVAILABLE FOR AERATION CONTROL/ MONITORING

Monitoring dissolved oxygen (DO) is the basic approach to measuring aeration performance. The activated sludge process hinges on adequate aeration to maintain the aerobic microorganisms responsible for converting organic materials into more stable solids that can be readily removed. Under-aeration or without sufficient DO, the plant risks the danger of pollution excursion by discharging uncontrolled solids and nutrients in the effluent water. Moreover, odors may generate and the bacterial characteristics might be negatively affected, when DO is not sufficient. Over-aeration, on the other hand, by running the blowers longer than necessary results in excessive energy use and higher O&M costs for the plant. The following discusses the various monitoring devices used in aeration control.

6.1 Traditional Practices

Throughout the history of wastewater treatment and control, three fundamental measurement guidelines were used to insure adequate and proper treatment of wastewater. They are:

- Appropriate treatment as measured by pH and DO
- Efficient treatment as measured by biochemical oxygen demand (BOD) and chemical oxygen demand (COD)
- Optimum treatment as measured by DO, ammonium, nitrate, nitrite, and phosphorous

Appropriate treatment is to insure that the wastewater can be reasonably treated by a biological process. The pH is the best indicator for wastewater which must be in the range of 6.0 to 9.0. Microorganisms will not survive well outside this pH range beyond which the wastewater is either too acidic or alkaline. Oxygen is needed in the form of DO (1-2 mg/l) to insure aerobic microorganisms will grow. These are the two essential parameters to run a wastewater treatment plant.

Efficient treatment is, during the treatment process, to maintain a sufficient amount of DO for growth and metabolism of microorganisms. A DO of 1-2 mg/l is typically sufficient in an aeration tank. BOD and COD are analytical quantities used to determine the quantity of oxygen that will be required to stabilize biologically or chemically the organic matter present. BOD_5 is an indirect measurement of carbon compounds by direct measuring the amount of oxygen consumed by the microorganism at a temperature of 20^0C within 5 days. Knowing the difference of BOD_5 levels from inlet and discharge of the wastewater plant makes calculation of the cleaning efficiency easy and accurate.

Optimum treatment is to adjust the DO to achieve the best effluent quality depending on the type of microorganisms and wastewater matrix. Performance effectiveness is measured by the lowest values of nitrate, nitrite and phosphorous concentrations in the effluent stream. These are considered nutrients which are the parameters that environmental regulatory agencies have imposed strict limits on their discharge. These parameters can be removed only through optimizing plant performance involving tertiary or advance treatment.

Basic Instrument of Measurement:
The basic instrument to measure wastewater parameters is a “3 in 1” hand held meter, for measurements of pH, DO, and temperature. This handy, easy to use, robust and waterproof instrument performs with low costs the most important parameters for wastewater monitoring. The meter comes complete with sensors, calibration- and maintenance solutions for pH, DO and temperature measurement in a rugged field carrying case. On-line monitoring is advisable for continuous measurement of basic parameters for wastewater performance. Occasionally, other parameters such as flow rate, turbidity, residual chlorine, and nutrients (ammonia and phosphorous) are also monitored for quality control and on as needed basis.

6.2 More Recent Point Source DO Monitoring

Today’s DO monitoring is based on a network of DO measuring probes. These probes are essentially fuel cells, with a semi-permeable membrane placed ahead of the electrode. This membrane allows the selective passage of oxygen molecules towards the electrode. The fuel cell chemically consumes the dissolved oxygen returning a voltage signal. The signal is proportional to the concentration of oxygen in the water solution.
When properly cleaned and maintained, DO probes offer instantaneous point-source readings of dissolved oxygen concentration in aeration basins. A major drawback of DO control systems is they do not quantify the oxygen transfer efficiency, but only measure the local values of DO concentrations. This equals to say that DO quantifies an effect of aeration, but not the efficiency of it. Same DO values can be achieved with very different OTE values. Wastewater treatment plant operators with DO control systems oftentimes use line headloss and flowrates to estimate energy costs. Although, DO control systems measure an effect of mass transfer, they do not quantify the mass transfer itself.

Proper control of DO in wastewater treatment is essential for microorganism health and viability, solids breakdown, BOD removal, odor control and operational cost containment. Most operators control the aeration process by placing their aerators on timers or by manually turning them on and off. Decisions to increase or decrease aeration time are usually made by guesswork or the occasional laboratory spot DO tests. If a heavy load of organic matter is sent to the aeration basin when the aerators are partially on, or just after a satisfactory spot DO check, oxygen is rapidly consumed without adequate oxygen presence and the aeration basin’s performance is compromised.

Conversely, when operating the aerators by timer or DO spot check, over-aeration frequently occurs, driving oxygen levels much higher than they need to be. Common practice indicates that DO levels usually run between five and thirteen mg/l. This is two to three times higher than necessary. By maintaining DO levels at this level significantly increases electricity usage and operational costs.

Advantages of DO Monitoring:

- Direct measure of dissolved air content and not the amount of air fed to the system
- Widely used by almost all plants
- Simple to use and controls energy usage by controlling the DO content of wastewater

Disadvantages of DO Monitoring:

- DO control systems do not provide information on the status of the diffusers, therefore on their operating efficiency, which is necessary to calculate energy requirements.
- Inaccurate readings - lag time between measured DO and the actual DO due to diffusion time required through the probe membrane
- Time lag produces a time delay for regulation of valve openings
- Slime buildup around the membrane may require periodic cleaning of the probes

6.3 Improved On-line DO Monitoring Technologies

In addition to the more common DO monitoring methodology, there are two other approaches that have been utilized to monitor activated sludge treatment performance: the Oxidation Reduction Potential (ORP) and Respirometry. Both of these monitoring technologies measure directly or indirectly the oxygen uptake rate (OUR) which correlates to the dissolved oxygen in the wastewater.

6.3.1 Oxidation Reduction Potential (ORP)

ORP is a measure of the redox potential. It is an effective way of measuring the oxygen source that is available to microorganisms. While a DO meter is a good way of measuring residual dissolved oxygen, it does not give an accurate representation of the oxygen source for low DO values (<0.2 mg/l). ORP can be a very useful tool for monitoring wastewater quality "on-line", in particular for nutrient removal. In general, the ORP values increase dramatically as organic matter is removed along the aeration tank, indicating the improvement of the bulk liquor redox status. At low wastewater pollutant concentrations, the ORP and dissolved oxygen inside the activated sludge aggregates are higher than those from medium-strength wastewater.

6.3.2 Respirometry

Respirometry is the measurement of the rate of oxygen uptake and interpretation of the biological oxygen consumption rate under well defined experimental conditions. Because oxygen consumption is directly associated with both biomass growth and substrate removal, respirometry is a useful tool for monitoring and control of the activated sludge process. Respirometers have evolved from the original simple manually operated BOD-bottles to now-a-days fully self-operating instruments that automatically perform sampling, calibration, and calculation of respiration rate. All respirometers are based on some technique for measuring the rate at which biomass takes up dissolved oxygen (DO) from the liquid or oxygen update rate (OUR). This can be performed directly by measuring DO or indirectly by measuring gaseous oxygen. Measurements can be performed either by electrochemical, paramagnetic, manometric, or volumetric methods. Currently about 50% of the commercial respirometer brands are based on a DO sensor type.

6.3.3 UCLA's Off-Gas Monitoring

The off-gas technology was developed by Redmon et al. in 1983. This technique assumes that the inert gases (nitrogen, argon) are conserved and can be used as a tracer. The oxygen mole ratio of dry air is known and can be compared to the mole ratio of the off-gas which can be experimentally determined by measuring the oxygen, carbon dioxide and water vapor partial pressures. This approach consists of measuring the partial pressure of oxygen in the gas stream leaving the wastewater. Since the oxygen partial pressure in the gas feed line is known, the percent of oxygen transferred to the wastewater can be represented by oxygen transfer efficiency (OTE). The OTE is the ratio of oxygen transferred to oxygen fed to the ASP. This value can be normalized to standard conditions as clean water (at 20^0C, 0 mg/l DO, 1 atm., and no salinity) as SOTE. Furthermore, process water that is deviated from clean water can be characterized by an α factor or the ratio of the mass transfer coefficient of process water to clean water.

Basic components of the off-gas testing equipment consist of an oxygen purity meter with its fuel cell electrode, an airflow meter, a temperature gauge, a pressure gauge, and the portable floating hood for capturing the off-gases. The oxygen purity meter with its fuel cell electrode monitors the dissolved oxygen content in the wastewater. The airflow meter, temperature gauge, and the pressure gauge are measuring devices needed to determine the field overall mass transfer coefficient K_L a (aeration efficiency) at steady state conditions.

6.4 Other Competing Technologies

Three other technologies that have also been reported in the literature include the radio active tracer procedure, the Steady State Method, and the Non-steady State Method. All of these methods, including the off-gas Method were evaluated and compared by the ASCE Oxygen Transfer Standards Subcommittee in 1981 at seven wastewater aeration site under process conditions. The following is a brief description of these technologies.

The radioactive (radio) tracer method is a technique for measuring gas transfer rates in any aeration system in the field or laboratory, for wastewater or clean water using inert gaseous tracers. The procedure is based on the principle of direct measurement of an inert tracer gas, krypton-85. The mass transfer rate for krypton-85 is related to the oxygen transfer rate by a constant that has been derived from theoretical and experimental investigations. This method depends on the simultaneous use of two tracers in a single aqueous solution: a dispersion/dilution radiotracer (tritiated water molecule) and a dissolved gaseous radiotracer for oxygen (krypton-85). The radio tracer procedure is considered by many researchers as the state-of-the-art technology for oxygen transfer rate measurement. However, this method only measures a bulk average α K_La and not an average of the local oxygen transfer efficiencies. Because of this, the radio tracer method may be more prone to errors resulting from air rate measurements when compared to the off-gas method.

The non-steady state method is another method for determining the average oxygen transfer coefficient, K_La_f under actual process conditions. This approach involves measuring the DO concentration over time after a perturbation (using H_2O_2) from the steady state condition. Basic assumptions, utilized in the non-steady state analysis, require the following: 1) a completely mixed system, 2) constant OUR and K_La_f , and 3) equal tank volume for probe sensing. H_2O_2 is used to raise the DO concentration in the aeration tank without changing power levels for the perturbation. This technique, however, cannot be used in clean water because dissociation generally does not occur or occurs over long time periods. The precision among multiple non-steady state tests, as measured by the coefficient of variation of OTE values, is generally better than 10%.

The Steady State Method requires that the rate of DO change be zero at any given point in the test volume. The only way to maintain a steady load and K_La is to operate the treatment system under batch instead of continuous flow conditions. Batch condition, however, does not realistically measure true field transfer rates of alpha values under normal loading conditions. For this reason, the Oxygen Transfer Standards Committee did not include the steady state method as a credible testing method.

From the analysis of the four testing methods, the off-gas procedure is unique in that it is the only one that measures the fraction of oxygen transferred from the gas stream directly. All the other methods (the liquid phase methods) determine the K_La. For these methods relying on K_La determinations, errors in applied air flowrates proportionally affect OTE computations and oxygen transfer rate. off-gas method, however, measures OTE directly and the rate of gas flow leaving the liquid surface, accurate plant air flow is not critical though desirable.

7.0
ANALYSIS OF THE OFF-GAS TECHNOLOGY

The off-gas technology, as deployed by the UCLA staff, is a gas phase mass balance technique for directly measuring oxygen transfer efficiency of aeration devices with a diffused air component. The method requires the use of a suitable analyzer for accurately measuring the relative gas-phase oxygen content of the ambient air and off-gas exiting the surface of an aerator. To accomplish this measurement, one or more floating hoods are required to capture and analyze the off-gases. At present, one major drawback of the off-gas technology is that the analysis instrument is large, heavy, and fragile, requiring a crew of several people to operate. In addition, the floating hoods needed for the testing are often too large and cumbersome to be transportable for in-situ field measurements.

7.1 Factors that Affect Estimation of OTE Field Testing

A report prepared by the ASCE Oxygen Transfer Standards Subcommittee in 1981 concluded that several factors could influence the estimation of OTE field testing. The potential impacts of these factors are presented and reproduced in the following table.

Factors	Oxygen Transfer Test			
	Steady State	Non-Steady State	Off-gas	Inert Gas Tracer
Sensitivity To				
Variation in				
• Influent wastewater flow rate	-	-	+	+
• Oxygen uptake rate	-	-	+	+
• Alpha	-	-	+	+
• DO concentration	-	-	+	+
• Product of airflow rate x KLa	-	-	+	0
Accurate measurement of				
• Oxygen uptake rate	-	+	+	+
• DO concentration	-	-	+	+
• DO saturation value	+	+	1	+
• Air flow rate	-	-	1	-
• Other	+	+	2	3
Costs				
Manpower	+	0	0	0
Analytical	+	+	0	-
Capital investment	+	+/0	0	-
Calculations	+	0	0	0
Estimated Precision	-	0	+	+

Note:

1 Calculate OTE directly

2 Requires accurate measurement

3 Requires accurate estimate of the ratio of K_{tracer}/K_La
\+ Positive response (e.g., not sensitive, less costly, more precise, easier)
0 Intermediate response
\- Negative response

Based on the above table, it is apparent that the inert gas tracer method has the broadest applicability since it can be used for both mechanical (surface aeration) and diffused air (subsurface aeration) devices. The steady state and the non-steady state methods generally are not applicable to plug flow reactors where alpha, DO, backmixing, and applied air flow rate vary throughout the basin. The tracer method, though less affected by the above factors, also are not ideally suited for use in plug flow regimes. The off-gas procedure is well suited to measure localized performance throughout the basin with respect to OTE, air flow rate, and for evaluating the process water performance of diffused aeration system in plug flow and complete mixed reactors.

7.2 Advantages and Limitations of the Off-Gas Technology

Based on the information gathered and evaluated above, the following is a summary of the benefits and potential drawbacks of the off-gas technology.

Advantages of off-gas Technology:

- Able to evaluate aeration devices under process conditions without process interruptions
- Measures directly mass transfer for determining oxygen transfer efficiency
- Measurements are real time data involving no lag time
- Complementary to DO measurements for controlling over-aeration
- Have exceptionally good precision and accuracy as compared to other methods

Disadvantages of off-gas Technology:

- Technology is not generally applicable to mechanical aeration systems
- Severe foaming may complicate gas sampling
- Current monitoring system (gas collection device) is bulky and difficult to use
- Skilled labor is required to operate and monitor performance
- Actual monitoring is labor intensive (requiring 3 to 4 skilled technicians on-site to manipulate the bulky/heavy equipment), time consuming, and costly

7.3 Advantages and Limitations of the Oxidation Reduction Potential Technology (ORP)

Similarly, we can summarize the potential strengths and weaknesses of the ORP technology:

Advantages of ORP Monitoring:

- Simple to use and quicker results than BOD/COD measurements
- Can be used for on-line monitoring to determine aeration performance

- Literature data shows a good linear relationship between ORP and chemical oxygen demand (COD); ORP can, therefore, be used directly to provide correlatable instantaneous treatment performance

Disadvantages of ORP Monitoring:

- Does not measure aeration performance directly as in DO monitoring
- Not commonly used by the wastewater industry
- Lack of technical and operational training for most treatment facilities to use it for on-line monitoring
- Need development of empirical correlations of ORP with DO and BOD_5 for routine use

7.4 Advantages and Limitations of the Respirometer Technology

For respirometer applications, one can also draw similar comparisons of its strengths and possible weaknesses:

Advantages of Respirometer Monitoring:

- A good indicator of activated sludge process condition and performance
- Can be used for on-line monitoring
- Useful technique for monitoring, modeling, and control of the activated sludge process
- Extremely versatile in process control and modeling research

Disadvantages of Respirometer Monitoring:

- Not commonly used in operational wastewater facilities
- Mostly used in research environment to extract information with a particular biological significance
- Sometimes difficult to interpret measured results because all oxygen consuming processes (heterotrophic substrate removal and nitrification) contribute to the observed total respiration rate of the biomass

7.5 Comparison of the Off-Gas Technology to other ASCE Monitoring Technologies

The following is a summary discussion based on a report published by the ASCE in 1996 on the comparison of the three field testing techniques: non-steady state, off-gas, and inert-gas tracer ("Standard Guidelines for In-Process Oxygen Transfer Testing").

- Under testing conditions of constant flow and oxygen uptake rate, all three techniques produce field oxygen transfer coefficients within ± 10% of each other
- Only off-gas method provide both point source values and overall basin transfer data; the other two provide only overall mass transfer measurements
- Non-steady state testing requires constant loading (OUR) conditions and the presence of DO; but costs for testing is the lowest of the three

- Inert gas tracer technique depends on a correct estimate of the krypton-to-oxygen mass transfer coefficient ratio. It also requires special license and is the most costly test
- Off-gas method also needs to be precise but does not require constant load or positive DO in the basin
- Steady state using OUR, simplest procedure to conduct, is not recommended because of significant inaccuracies due to either overestimation or underestimation of the real oxygen transfer rate

7.6 Potential Applications of the Off-Gas Technology to Other Industries

In addition to traditional use of the off-gas technology for municipal wastewater applications, this technology can be readily adapted with minimum modifications for application to industrial wastewater treatment. Examples of these applications may include any of the following industries: food processing, chemical, and/or pharmaceutical industry wastewaters. Applications are neither currently common nor well known for these industries. Only limited research applications have been reported in the literature. It is believed, however, that there are no major barriers to its technical potential. The marketability of this technology for industrial wastewater monitoring, however, on a realistic basis is still not a near-term replacement option.

8.0
POTENTIAL BENEFITS OF THE OFF-GAS TECHNOLOGY FOR AERATION MONITORING

There are over 120 medium to large wastewater treatment plants, with throughput capacities greater than 2 MGD, in SCE service territory (based on SCE database). Approximately 80% of these plants use aeration as their main secondary treatment process. All these plants can benefit from the use of this off-gas monitoring technology. Assume that an average plant consumes 2,500 kWh/MG (based on recent CEC publication) of which 65% is utilized in aeration (1625 kWh/MG) and an average size plant is 5 MGD. Maximum energy savings achievable (assume conservatively 25% savings from over-aeration) at these plants would be:

1625kWh/MG x 5MGD x 365days/yr x 96 plants x 0.25 = 71.18 million kWh/yr.

Since the implementation of this project requires little or no capital funding, and most treatment plants are eager to reduce their energy costs, the penetration rate for this project should be rather high.

Assume 30% penetration (or approx. 30 plants), a maximum potential of energy savings in the amount of 25.6 million kWh annually is achievable. Conservatively, this can be implemented over a five year period. The actual penetration rate per year would be 6% (or six plants) and kWh saving per year would be = 71.18 x .06 = 4.27 million kWh/yr

9.0
SUMMARY CONCLUSIONS

Based on the study results, the following are the most significant conclusions reached:

- An overview of the wastewater aeration processes was undertaken, including energy usage significance and process intricacies, to give a broad perspective of the technologies involved in wastewater aeration and corresponding design requirement needs.
- Various monitoring methods including historical practices, conventional approaches and recent developments were discussed. Specific monitoring methods of interest reviewed include: oxidation reduction potential (ORP), respirometry, off-gas monitoring, steady state method, non-steady state method, and inert gas tracer method.
- Three commonly used technologies including the off-gas, ORP, and respirometer methods were further analyzed. Advantages and disadvantages of each method were presented to illustrate their strengths and weaknesses.
- Comparisons were also made of four technologies including steady state, non-steady state, off-gas and inert gas tracer methods, based primarily on ASCE Oxygen Transfer Standards Subcommittee's findings in 1981. It was stated that although inert gas tracer has the broadest application for both mechanical and diffused aeration, the capital investment and complex analytical requirements needed to support its application make it difficult to consider the inert gas tracer as the method of choice for aeration monitoring.
- It is concluded, based on compiled information, that off-gas technology is the method of choice for monitoring wastewater aeration performance with respect to oxygen transfer efficiency (OTE). This technology, as currently evaluated by the UCLA research group, is well suited for evaluating process water performance in diffused aeration systems for both plug flow and complete mixed reactors.
- Because of it current bulky configuration and weight, and the training necessary to utilize the off-gas analyzer, the off-gas method is not commonly used at present by wastewater treatment plant operators. Off-gas methodologies utilized for OTE measurements are also overly complex and time consuming to implement. There is a definite need to simplify the measurement methodology and to reduce the size and weight of the off-gas monitoring instrument. It is also noted that the sampling hood sizes need to be minimized/ optimized for ease of operation and for labor cost reductions.

10. 0
SUMMARY RECOMMENDATIONS

Recommendations regarding the current UCLA research:

- Current off-gas monitoring equipment is bulky, difficult to handle, costly, and labor intensive to perform routine monitoring. Because of these constraints, the technology is not widely used by the wastewater industry for routine monitoring. It is recommended, therefore, that the current funding for the UCLA research to develop a prototype unit with reduced size, weight, and costs of the off-gas equipment be encouraged and continued. Potential benefits will result in broad adoption with the potential for significant kWh/yr savings from energy reduction in wastewater aeration.

Recommendations for future considerations should also include the following:

- There are three major components that can have a major impact on aeration performance and optimization. They are: UCLA's research on optimizing monitoring device to improve oxygen transfer efficiency, blower control for aeration equipment modulation, and SRT/DO optimization for process control. What we need is a three-pronged approach to cost-effectively address the full spectrum of potential benefits from wastewater aeration.
- Blower control to improve energy efficiency in wastewater aeration: The objective of this project is to develop a manual or guidance document to allow wastewater treatment plant operators to improve energy efficiency through equipment adjustment. This process, dissolved oxygen control, includes the dynamic range or the "turn up" or "turn down" capabilities of the equipment (blowers) which supply the air to the aeration system. Conservatively, aeration modulation can save 20% of the energy utilized in wastewater aeration; this would translate to an average of 0.27 million kWh/yr. per treatment plant. Approximately 71.2 million kWh/yr energy savings can be realized from application.
- SRT/DO Optimization is another approach for improving process control of the aeration system. Solids retention time (SRT) and dissolved oxygen (DO) are two operating parameters that can effectively control the performance of wastewater aeration. Typically SRT is operated in the range of 5 to 15 days and DO is maintained between 1.0 to 2.0 mg/l. For organics removal, DO is typically maintained at or near 1.0 mg/l and for nutrients removal (nitrification/de-nitrification), it is maintained at or near 2.0 mg/l. Although the generic software for optimizing SRT and DO as well as selecting the set points for the optimized system has been developed by Ekster and Associates, Inc. in 2005 through a CEC funding grant, its application is still not commonly used. To facilitate and broaden its implementation, we need to develop nomographs to evaluate potential energy savings for plants without this software. It is estimated that with this information,

plants can realistically develop customized software to save as much as 90,000 kWh/million gallons per year.

- In addition to wastewater aeration, there are a number of other unit processes and operations within the wastewater treatment system that can also be optimized to achieve additional energy savings. One approach is to benchmark this industry by developing an energy use profile for individual unit processes with specific process equipments based on wastewater load and discharge requirements. Software models can be developed to simplify calculation of potential energy savings based on individual or combinations of process optimization and equipment replacements. This software based model can be user-friendly and cost-effectively implemented at all wastewater treatment plants with activated sludge systems.

11.0
REFERENCES

1. Activated Sludge Principles, www.swibic.org/envengr/secondary/principles/activated_sludge.html.
2. American Society of Civil Engineers, Standard Guidelines for In-Process Oxygen Transfer Testing, ASCE -18-96, ASCE, 345 East 47th Street, New York, NY 10017, 1996.
3. Babcock Jr., R.W. and Stenstrom, M .K., Precision and Accuracy of off-gas Testing for Aeration Energy Cost Reduction, Water Environment Federation, 66th Annual Conference & Exposition, CA, October 1993.
4. Bolles, S. A., Modeling Wastewater Aeration Systems to Discover Energy Saving Opportunities, Process Energy Services, LLC.
5. Boyle, W. C., Stenstrom, M. K., Campbell, Jr., H. J., and Bremmer. R. C., Oxygen Transfer in Clean and Process Water for Draft Tube Turbine Aerators in total Barrier Oxidation Ditches, Jour. WPCF, Vol. 61, No. 8, Aug. 1989.
6. Capela, S., Gillot, S. and Heduit, A., Comparison of Oxygen Transfer Measurement Methods under Process Conditions, Water Environmental Research, Vol. 76, No. 2, March/April, 2004.
7. Davis, R. N. and Lettman, G., Optimization of Wastewatr Treatment Plants: Dissolved Oxygen and Suspended Solids Measurements, www.wioa.org.au/conf_papers/99/paper.htm., 1999
8. Forster, S., Efficient Wastewater Treatment, The Field for Analytical and Monitoring Equipment, www.eco-web.com, July, 2000.
9. Gernaey, A. K., Petersen, B. and Ottoy, J. P., Activated Sludge Monitoring with Combined Respirometric-Titrimetric Measurements, Wat. Res. Vol 35, No. 5, 2001.
10. Kiser, P., Efficient DO Monitoring is an Effective Treatment Strategy, www.baumpub.com
11. Krause, S., Cornel, P. and Wagner, M., Comparison of Different Oxygen Transfer Testing Procedures in Full Scale Membrane Bioreactors, Darmstadt University of Technology, Institute WAR, Petersenstraze 13, D-64287 Darmstadt, Germany.
12. Li, B. and Bishop, P. L., The Application of ORP in Activated Sludge Wastewater Treatment Processes, Environmental Engineering Science, Vol. 18, No. 5, Sept. 2001.
13. Metcalf & Eddy, Inc., Wastewater Engineering, Collection, Treatment and Disposal, McGraw Hill Book Co., New York, 1972.
14. Michaud, M., Libby, T. Flanders, K. and others, Choosing the Right Aeration System, Lagoon Systems in Maine, An Informational Resource for Operators of Lagoons, www.lagoonsonline.com/finebubble.htm., May, 2005.

15. Redmon, D., Boyle, W.C. and Ewing, L., Oxygen Transfer Efficiency Measurements in Mixed Liquor using off-gas Techniques, Jour. WPCF, Vol. 55, No. 11, Nov. 1983.

16. Risk Reduction Engineering Laboratory, Center for Environmental Research Information, Design Manual, Fine Pore Aeration Systems, EPA/625/1-89/023, U.S. EPA, Cincinnati, OH 45268, September 1989.

17. Stenstrom, M. K., Upgrading Existing Activated Sludge Treatment Plants with Fine Pore Aeration Systems,, Wat. Sci, Tech., Vol. 22, No. 7/8, 1990.

18. Stenstrom, M.K. and Redmon, D. T., Oxygen Transfer Performance of Fine Pore Aeration in ASBs – A Full Scale Review, International Environmental Conference & Exhibits, 1996.

19. Types of Activated Sludge Processes, www.cee.vt.edu/program_areas/environmental/teach/gwprimer/group12/types.htm.

20. Vanrolleghem, P. A., Principles of Respirometry in Activated Sludge Wastewater Treatment, Universiteit Gent, Department of Applied Mathematics, Biometrics and Process Control, October 2002.

21. Water Engineering Research Laboratory, Fine Pore (Fine Bubble) Aeration Systems, Summary Report, EPA/625/8-85/010, Cincinnati, OH 45268, Oct. 1985.

22. Watts, J.B. and Cavenor-Shaw, A. R., Process Audit and Asset Assessment using on-line Instrumentation., www.msluk.demon.co.uk, 2004