Water Environment Federation
the water quality people

FACT SHEET

Liquid Stream Fundamentals: Diffusers

Aeration systems are a key element of successful biological treatment at water resource recovery facilities (WRRFs). Aeration diffusers are commonly implemented to meet carbonaceous and nitrogenous oxygen demand due to their higher Oxygen Transfer Efficiency (OTE) per kWh compared to other aeration technologies (i.e. mechanical aerators). Aeration typically comprises the largest electrical demand at wastewater facilities, therefore proper diffuser selection and operation is key to managing electrical costs at facilities while meeting treatment objectives.

Introduction

The primary purposes of aeration diffusers are to transfer oxygen into the process to support biological treatment and to provide minimum mixing energy to prevent solids from settling in the secondary reactors. Numerous materials are utilized to manufacture porous diffusers, which can be divided into two categories: rigid and flexible. Rigid diffusers are usually constructed from ceramic media such as alumina, corrosive resistant metal, and plastic. Flexible diffusers include membranes composed of thermoplastics or elastomers (MOP 8). Flexible diffuser technologies include membrane discs, tube, strip and panel diffusers. Low pressure air is delivered to the diffusers from the blower system. The air travels through the air piping network to a vertical section of pipe called a dropleg, which leads to the floor of each reactor zone. The diffusers are installed in a grid layout, which uses distributor piping to distribute the air to each diffuser in the aerated zone.

The primary benefit of aeration diffusers over mechanical aeration is that less energy is consumed to transfer the equivalent mass of oxygen to the process. Diffused aeration can also enable improved dissolved oxygen (DO) control through higher efficiency and properly designed grids designed to match the oxygen demand, thus increasing process performance and reliability.

Figure 1— Fine Bubble Diffused Aeration System in Action. Photo courtesy of Napa Sanitation District.

Process Description

Diffused aeration is utilized in biological treatment processes to facilitate oxygen transfer to the bulk liquid for chemical and biological reactions. Aerobic processes rely on chemoheterotrophic and chemoautotrophic metabolism in which oxygen is the electron acceptor. The amount of oxygen that must be transferred depends on the treatment goals for carbonaceous and nutrient reduction. Suspended growth processes that are designed to achieve carbon oxidation must be supplied with sufficient oxygen to facilitate carbonaceous biochemical oxygen demand (cBOD) oxidation. Many WRRFs must provide both nitrification and carbon oxidation, and therefore they must also meet the nitrogenous oxygen demand.

Oxygen transfer, as a sparingly soluble gas, can be modeled though the two film theory (Lewis et al. 1924). Diffuser systems, which produce smaller bubbles, are more efficient at transferring oxygen to the bulk liquid, since more surface area is available to transfer oxygen relative to volume. The alpha factor (α) adjusts the oxygen transfer rate to account for variations in wastewater characteristics, aeration tank layout, and aeration system equipment. The alpha factor is expressed as the ratio of liquid-side mass transfer coefficient ($k_l a$) in process water to the $k_l a$ in clean water.

$$\alpha = \frac{k_l a_{Process\,Water}}{k_l a_{Clean\,Water}}$$

Alpha values range from approximately 0.3 to 1.0 (M & E), depending on the type of aeration equipment used. The oxygen transfer rate (OTR) is described by the equation below:

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

$OTR =$	Oxygen transfer rate (kg O_2/h)
$k_l a =$	Liquid-side mass transfer coefficient (h^{-1})
$DO =$	Dissolved oxygen in water (kg O_2/m^3)
$DO_{sat} =$	Dissolved oxygen in water at saturation (kg O_2/m^3)
$V =$	Water volume (m^3)

OTE is the relationship of how much oxygen is dissolved into the bulk liquid relative to the original oxygen released into the reactor through a diffuser system. This relationship is described in the equation below:

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

$OTE =$	Oxygen transfer efficiency (%)
$O_{2\,in} =$	Oxygen mass flow rate into the reactor
$O_{2\,out} =$	Oxygen mass flow rate out of the reactor

Standard oxygen transfer efficiency (SOTE) corrects the OTE calculated above to standard atmospheric pressure: 101.3 kN/m^2 (14.7 lb_f/in^2), 20°C (68°F), and a TDS concentration of 0 mg/L.

Diffused aeration systems are comprised of a low pressure blower system, piping to convey the air to the reactors, diffusers, and often control valves and monitoring instruments. This system is used to distribute the air to meet the oxygen demand within the biological reactor. For more details on blowers and aeration control, see Aeration Design and Blower Fundamentals fact sheets.

Aeration System Components

Air headers and droplegs. Header piping is used to convey the low pressure air from the blower system to the reactors. Common materials of construction include stainless steel or coated steel pipe. Mechanical expansion joints must be included in the pipe system to address thermal expansion. Droplegs convey the low pressure air from the main header to the diffusers located at the bottom of the reactor. The droplegs are anchored to the reactor wall and typically include, as a minimum, an isolation valve accessible from an above tank deck. Airflow meters are typically installed at an accessible location on the air header or droplegs. Venturi and thermal dispersion airflow meters are commonly used to provide real-time airflow monitoring. Actuated control valves are installed on the air headers or droplegs depending on aeration system design. These valves are actuated to distribute air among aeration grids and tanks in service.

Figure 2— Droplegs and disc diffuser grids. Photo courtesy of Napa Sanitation District.

Diffuser grid / layout. The diffuser grid is designed to evenly distribute air within each aerated zone. Often, the dropleg connects to a manifold and then to distributor pipes. The diffuser holders are then mounted onto this distributor by solvent welding or a mechanical connection. Panel type diffusers are typically connected to the manifold pipe via a flexible hose.

Diffuser system anchors. Rigid anchoring fixtures are utilized to resist the buoyant forces on the grid and to ensure all the diffusers are level and at the same depth. These fixtures can also be designed to allow the diffuser system to resist hydrodynamic forces within a reactor. More robust supports are needed when mechanical mixing is included in the same zone as the diffusers. Often this anchoring system is comprised of threaded rods which are imbedded into the reactor floor. Support brackets join the aeration grid or panel frame to the threaded rod. The materials of construction for anchoring systems are typically stainless steel.

Figure 3— Example diffuser anchor system. Photo courtesy of Xylem.

Diffuser purge system. Diffuser purge systems should be installed to facilitate removal of moisture from the fine bubble diffuser grids. Depending on environmental conditions, condensation from the low pressure air can collect in the grid piping. Also, prolonged periods of the aeration system being off can allow process water to enter the grid through the diffuser pores. The purge system is often comprised of a coarse bubble diffuser and/or a condensate purge line connected to the lowest point on the aeration grid. The coarse bubble diffuser constantly operates and drains the water from the aeration system. The condensate purge line operates based on an air-lift principal and is manually operated by an operator at the reactor surface.

Figure 4— Diffuser purge valve. Photo courtesy of Napa Sanitation District.

Diffusers. Porous diffusers are typically constructed from ceramic, thermoplastics or elastomers. Ceramic diffusers are produced with rounded or irregular shaped mineral particle bounded together to produce a network of interconnected passageways for air to pass through. Polymer based membrane diffusers are typically constructed of ethylene propylene diene monomer (EPDM). Additional membrane materials include high-density polyethylene (HDPE), polytetrafluoroethylene (PTFE), silicone, polyurethane and styrene-acrylonitrile (MOP 8). The membrane produces a discrete bubble size based on the pore size. These pores are created through slicing, punching or drilling holes or slits in the membrane. Each hole acts as a variable aperture opening in which the position is dictated by the membrane air flux. Typical perforation size for membrane diffusers range from 0.75 to 3 mm. A general summary of the major diffuser types is provided in Table 1 below.

	Description	Bubble Size	Typical Application
Ceramic Dome/ Disc	Dome or disc-shaped ceramic diffusers mounted on air-distribution pipes	Fine	Oxygen transfer for secondary treatment
Slotted Tube	Stainless-steel tubing containing perforation and slots to provide a wide band of diffused air	Coarse	Provide mixing energy
Single Drop	Devices typically constructed of molded plastic	Coarse	Provide mixing energy
Membrane Disc	Flexible perforated membrane supported on a disc support frame in a grid fashion	Fine	Oxygen transfer for secondary treatment
Membrane Tube	Flexible perforated membrane supported on a tube support frame in a grid fashion	Fine	Oxygen transfer for secondary treatment
Membrane Panel / Strip	Flexible perforated membrane supported on a rectangular support frame in a grid fashion	Ultrafine	Oxygen transfer for secondary treatment

Table 1— Diffuser Technologies. Table adapted from Design of Municipal Wastewater Treatment Plants (Manual of Practice No. 8), published by the Water Environment Federation and McGraw Hill

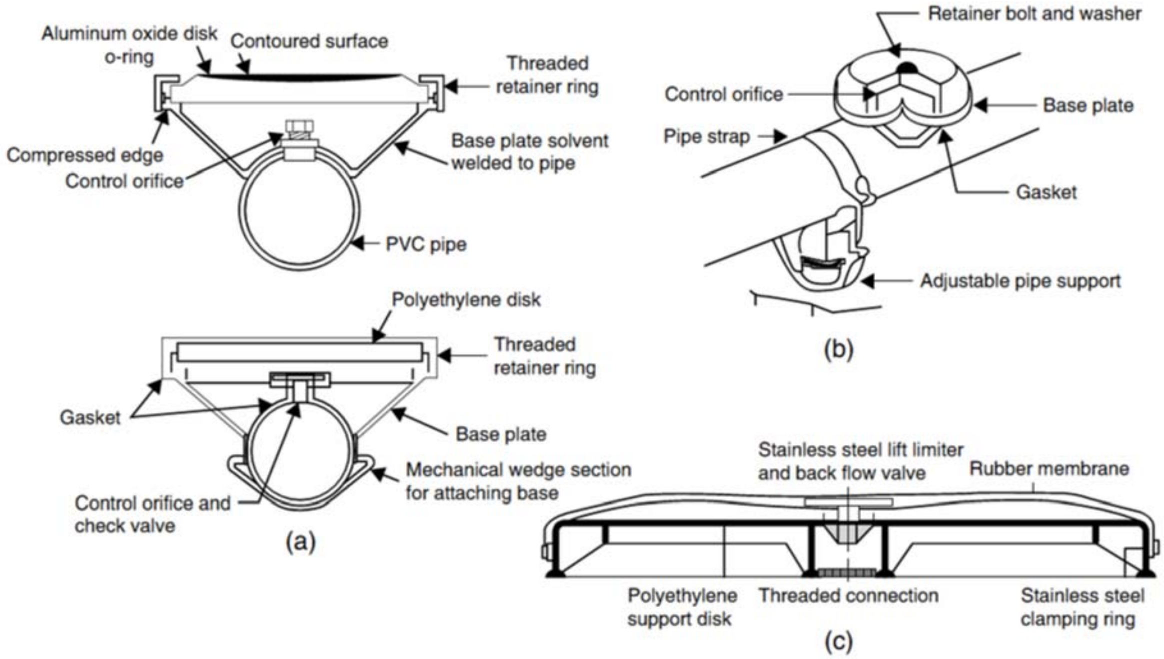
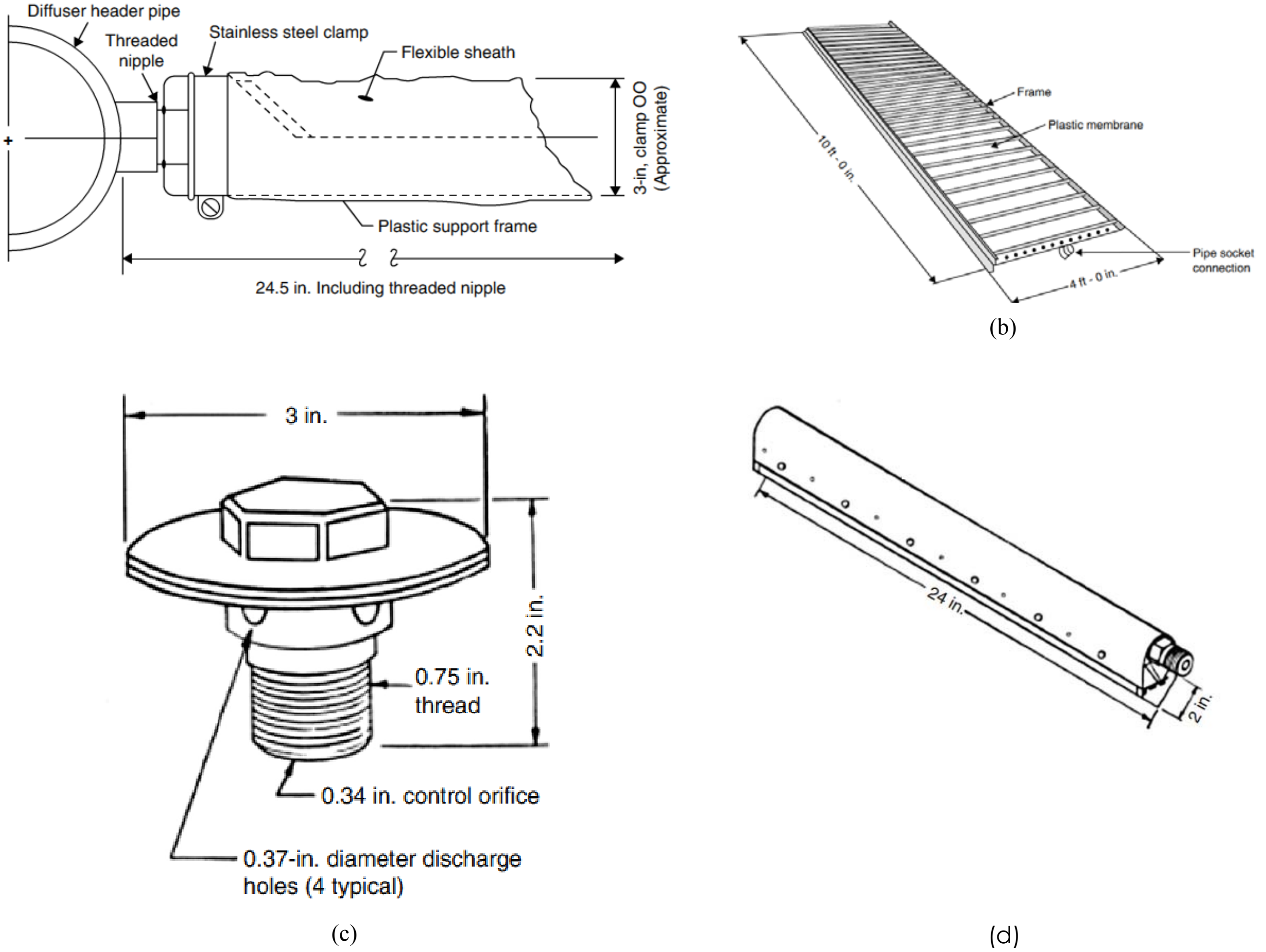


Figure 5— Diffuser technologies: (a) discs, (b) dome, and (c) membrane disc. Source: MOP 8.



(b)

(c)

(d)

Figure 6— Diffuser technologies (a) membrane tube diffuser, (b) membrane panel diffuser, (c) single drop diffuser, (d) slotted tube diffuser. Source: MOP 8.

Design

The design of diffused aeration systems begins with determining the oxygen demand of the process. The steps for this analysis are covered in detail in the Aeration Design factsheet. One key design factor for aerations systems is the alpha (a) factor. The alpha factor is the ratio of oxygen mass transfer rate in process water to that in clean water. The alpha factor represents the reduction in oxygen transfer rate due to surfactants in the influent wastewater. In general, the alpha factor, and thus the OTE, increases with longer mean cell retention times (MCRT) (Rosso et al., 2006a). The main mechanism for this observance is the more rapid and efficient removal or surfactant and readily-biodegradable COD (rbCOD) at higher MCRT. The alpha factor is dynamic and varies diurnally, spatially within a basin, and can be impacted by implementation of selector zones.

Diffuser flux. The diffuser flux (airflow per equivalent diffuser area) is dependent on the diffuser membrane material. Higher diffuser flux results in larger bubbles due to coalescing and larger pore size caused by membrane stretching. Larger bubbles result in reduced OTE. Lower diffuser flux results in smaller bubbles and increased OTE. Manufactures provide limits to diffuser flux in order to reduce buildup of biofilm and prevent damage from over stretching the membranes.

Diffuser density and taper. Diffused aeration systems in plug-flow aeration tanks are typically designed for tapered aeration, where there is a greater density of diffusers in the upstream end of the aeration tank compared to the downstream end. The greatest process oxygen demand and lowest alpha factor in a plug-flow tank will be the most upstream portion. Tapered aeration provides for a more equitable distribution of oxygen to meet the spatial variations in oxygen demand. The spatial distribution of oxygen demand will vary diurnally and daily depending on the flow and load pattern to the aeration tanks, wastewater temperatures, operational MCRT and other process variables. When designing for tapered aeration grids, room for operator access during cleaning of each diffuser should be considered.

Piping design. Piping for low pressure aeration service is typically constructed of steel or stainless steel depending on service and cost considerations. These piping systems should be designed for a minimum working pressure of 25 psig and

250 to 300 degrees Fahrenheit depending on local climate and diffuser submergence. Aeration piping must also include fixed supports, sliding supports, and expansion compensation. The aeration system piping should be evaluated to determine the anticipated thermal expansion of each major branch of the system. The appropriate number of expansion couplings are then determined and placed in conjunction with fixed and sliding supports to account for expansion and contraction in the piping network. Locations where the aeration piping changes planes or requires vibration isolation are examples of where expansion couplings should also be considered.

Operation and Maintenance

Aeration diffuser operation and maintenance (O&M) requirements will vary on a case-by-case basis for each facility and will be impacted by the manufacturer and site-specific conditions. The typical methods of diffuser operation and maintenance include, but are not limited to:

1. Physical cleaning
2. Chemical cleaning
3. Minimum mixing
4. Periodic flexing or bumping
5. Diffuser testing

Cleaning interval. During diffuser operation, biofilm and pore plugging occurs with time, which results in bubble coalescence and reduced OTE. This reduction in OTE reduces the advantage fine bubble diffusers have over other technologies and results in higher electrical costs as well as potential reduced treatment performance. A cleaning frequency can be determined that accounts for the net-present value of power costs and shows what interval is cost effective relative to the increased electrical costs that would be experienced operating fouled diffusers (Rosso et al., 2006b). Manufactures may require a minimum cleaning interval to maintain warranty conditions. When the tank is down for service, the aeration grid pipe and anchoring system should also be inspected for damage, wear, and proper level.

Figure 7— Aeration Bubble Size Before and After Cleaning. Photo courtesy of Dr. Diego Rosso.

The photo below demonstrates the reduction of coalescence and thus bubble size following diffuser cleaning.

Physical cleaning. The approach to physically cleaning aeration diffusers is recommended by each manufacturer. In general, the cleaning process includes draining the process reactor completely. The operators then can utilizes a hose with moderate pressure (less than 60 psig) to remove excess solids and biofilm. A soft bristle brush can then be used to remove attached biofilm, participates, or oil.

Minimum mixing. Aeration provides mixing energy to maintain the biomass in suspension. Due to the higher efficiency of fine bubble diffusers, the airflow for the later aerated zone(s) of an aeration tank can be dictated by the required mixing energy and not oxygen transfer requirements. Diffuser grids should be designed to provide the required OTR for each zone while also meeting the minimum mixing requirement for that zone. A general guide for minimum mixing is to provide at least 0.05-0.09 scfm/ft^2 of aeration tank area (MOP 8).

Chemical cleaning. This cleaning approach is site specific and typically only employed when access to the diffusers is limited or to reduce operational impacts caused by removing a process tank from service for physical cleaning. The approach to chemically cleaning aeration diffusers is recommended by each manufacturer depending on the diffuser product installed and dropleg material. In general, the cleaning process utilizes either a gaseous or liquid cleaning agent. Gaseous agents can include hydrochloric acid, which is injected into the air stream during normal operation of ceramic diffusers. The low pressure air carries the cleaning agent to each diffuser where it creates an acid solution capable of reducing mineral deposits and biological fouling. A newer technique utilizes a low strength liquid acid solution which is injected into the dropleg. This approach is safer than cleaning with hydrochloric acid gas.

Air bumping. Air bumping is a technique that can be employed for membrane diffusers between diffuser cleanings to reduce biofilm buildup. The general approach includes increasing the airflow to each diffuser grid for 5 to 10 minutes at least once a week. The procedure can vary by diffuser type and manufacturer. It is recommended that the manufacturers operation and maintenance manual be consulted for the specific bumping procedure. The bumping can be completed overnight, or when energy costs and process loading is reduced. The design of the bumping control should take into account blower and diffuser operating limits.

Diffuser testing. Diffuser testing can be utilized as a tool to evaluate clean water efficiency to compare diffuser manufactures and evaluate in-process diffuser performance. Clean water testing is completed using the ASCE standard procedure (ASCE, 2006). The results from this test are reported as SOTE. The general approach includes adding an oxygen scavenger to clean water and operating the diffusers while recording the DO in the test tank. The re-aeration slope is utilized to determine the k_la for the diffusers tested.

In-process testing is completed using the ASCE standard procedure (ASCE, 1997) to determine the real-time efficiency of aeration diffusers during operation. The most common method utilized is the off-gas method. A hood with known dimensions collects the air which leaves the surface of the water in the reactor. An oxygen analyzer is utilized to determine the oxygen mole fraction of the off-gas to determine the amount of oxygen that was transferred to the wastewater.

WEF Resources

1. Design of Municipal Wastewater Treatment Plants (MOP 8) (2017)
2. Energy Conservation in Water and Wastewater Treatment Facilities (2009)

Other References

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5. Rosso, D., Stenstrom, M. K. (2006a) Alpha Factors in Full-Scale Wastewater Aeration Systems. *Proceedings from the 79th Annual Water Environment Federation Technical Exposition and Conference [DC-ROM]; Dallas, Texas October 21-25, Water Environment Federation: Alexandria, Virginia.*
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7. Tchobanoglous, G, et al. Wastewater Engineering Treatment and Reuse, Metcalf and Eddy 4th ed. New York: McGraw-Hill Education, 2003.

Acknowledgments

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