DIFFUSED AERATION DESIGN GUIDE

INTRODUCTION

Those involved in the design of diffused aeration equipment for wastewater treatment should understand the impact that process type, maintenance issues and economic considerations can have on the selection of equipment. Like many other engineering challenges, these factors are frequently interrelated and trade-offs of one aspect versus another are required for most application. This design guide presents information that has been obtained and developed from a variety of sources. Some of this information has been developed from actual test data, some is condensed from other published sources, some is based on good engineering judgement and practical field experience. The information, formulas, values and methods, etc. should be viewed as a design aid and *may not be applicable in all situations*. The designer should always use good professional engineering judgement for every application.

The following sections of this design guide will briefly discuss the activated sludge process and biological treatment oxygen demands. The guide provides a rational step-by-step procedure to convert actual oxygen requirements (AOR) to standard oxygen requirements (SOR). It illustrates how to perform many of the oxygen transfer calculations including approximating aerator sizing and selection. Final equipment sizing and configurations should be referred to the factory for confirmation.

Oxygen must be provided in biological treatment systems to satisfy several types of demands. These are referred to as actual oxygen requirements or AOR. AOR is always expressed as “field conditions”. Each wastewater treatment plant has its own unique field conditions that include site elevation, temperature, working DO level, diffuser submergence and alpha and beta factors. The designer must use these factors to convert AOR to standard oxygen requirements (SOR) to properly apply the aeration equipment and determine the amount of process air required to satisfy the biological treatment oxygen demands. Common units of expression for AOR and SOR are pounds of oxygen per day per unit volume. SOR values will always be larger than AOR values. Confusion and misunderstanding can be minimized between designer and equipment supplier if the designer expresses his desired oxygen demands in terms of SOR values. If this is not possible, then clearly identify the oxygen demand as an AOR value and provide as much information as possible for the equipment supplier to assist you in making the appropriate AOR/SOR conversion. Experienced aeration equipment manufacturers can provide information to engineers and designers on the oxygen transfer capability of particular equipment and configurations when the equipment is aerating clear tap water. These tests, when corrected for temperature and elevation to standard conditions, become the basis for determining the equipment’s standard oxygen requirement or SOR. *Equipment manufacturers cannot guarantee the oxygen transfer capability of aeration equipment in wastewater*. Each wastewater treatment plant has its own unique field conditions and waste type that preclude this type of guarantee.

Equipment manufacturers can show engineers and designers a rational method to convert AOR to SOR and can offer advice on the probable values used in the AOR to SOR conversion. However, it is the engineer’s responsibility to determine the AOR of a particular system or process and select the appropriate conversion factors to relate AOR to SOR. Specifying an SOR value is the best way to prevent confusion and problems in the specifications.

ACTIVATED SLUDGE AND BIOLOGICAL TREATMENT

Activated sludge aeration tanks are the largest applications for diffused aeration equipment. These tanks and the associated air diffusion equipment are the heart of the activated sludge process and typically are the single largest energy user associated with plant operations. Energy costs for aeration will typically be 50% to 90% of all energy consumed at a wastewater treatment plant.

Oxygen must be provided in biological wastewater treatment systems to satisfy several types of demands. One demand is that associated with the oxidation of organic or carbonaceous materials. Carbonaceous oxygen demand is associated with two cellular functions: cell synthesis and endogenous respiration. Cell synthesis carbonaceous oxygen demand occurs when organic matter is first metabolized by the microorganisms contained in the mixed liquor. It is related to the oxygen required to oxidize a portion of the organic matter to provide the energy necessary for cell synthesis. Endogenous respiration carbonaceous oxygen demand occurs as the synthesized organisms are retained in the treatment system and it represents the essential life processes. The net result is that increasing amounts of oxygen are required as lower process organic loadings are used. Lower process organic loadings are characterized by operation at a longer solids retention time (SRT) and a lower food-to-microorganism (F:M) loadings.

Oxygen is also required for biological oxidation of ammonia nitrogen to nitrate nitrogen. If the process is designed and operated in a nitrification mode, the oxygen demand due to nitrification must be included in the calculation of oxygen requirements for the system. However, nitrification may also occur in systems where only carbonaceous BOD removal is required. When the wastewater is warm, say 20° C (68° F) or above, it may not be possible to operate the treatment system at a high enough loading or short SRT to prevent nitrification from occurring. Under these circumstances, oxygen transfer capacity to meet this additional demand must be provided, although not required by permit.

Oxygen is also required to oxidize inorganic materials in the influent wastewater. A good example is hydrogen sulfide, which is oxidized chemically when brought in contact with dissolved oxygen in the biological reactor. Reactions of this type can be quite rapid and can proceed to complete oxidation according to well-established stoichiometry. Process oxygen requirements will be reduced if denitrification occurs in the biological treatment system. Denitrification can occur under controlled conditions if the system is specifically designed with an anoxic zone for nitrogen removal. Designers seldom use the potential oxygen requirement reduction of “credit” when calculating all oxygen requirements, but rather assign this luxury oxygen as an additional safety factor in the overall design.

CALCULATING ACTUAL OXYGEN REQUIREMENTS - AOR

A number of approaches have been used to estimate the oxygen requirements caused by the biochemical oxidation of organic matter. Many regulatory agencies specify oxygen design criteria for various unit processes and some requirements are probably based on various empirical or rule-of-thumb techniques. More sophisticated approaches to estimating the oxygen demand in aeration systems may be obtained from various computerized process models. Unfortunately, most process models either require certain values that need to be experimentally determined for the particular waste or else must rely on past experience and judgement in selecting the model values. One rational approach to determine the oxygen requirements in the biological process is to total the oxygen demand due to the sources described below. The summation of all of these contributions must be considered in the sizing of the aeration system.

1. BOD LOADING

Figure 1 from the WPCF MOP 8 shows the relationship between SRT and pounds of oxygen required per pound of BOD removed at various temperatures for domestic wastewater in an activated sludge system. For typical SRTs of 5 to 10 days, the pounds of oxygen per pound of BOD removed varies, from 0.92 to 1.07. A value of 1.0 pound of oxygen per pound of BOD removed is commonly used. On occasion, some designers use a more conservative value of 1.1 pounds of oxygen per pound of BOD removed. In processes with long detention times (more than 18 hours) and low organic loadings where excess sludge is also oxidized in the aeration tanks, a higher value is justified. Examples where higher values are justified are extended aeration and oxidation ditches. In these cases, supplying 1.25 to 1.80 pounds of oxygen per pound of BOD removed or higher is appropriate.

2. AMMONIA LOADING

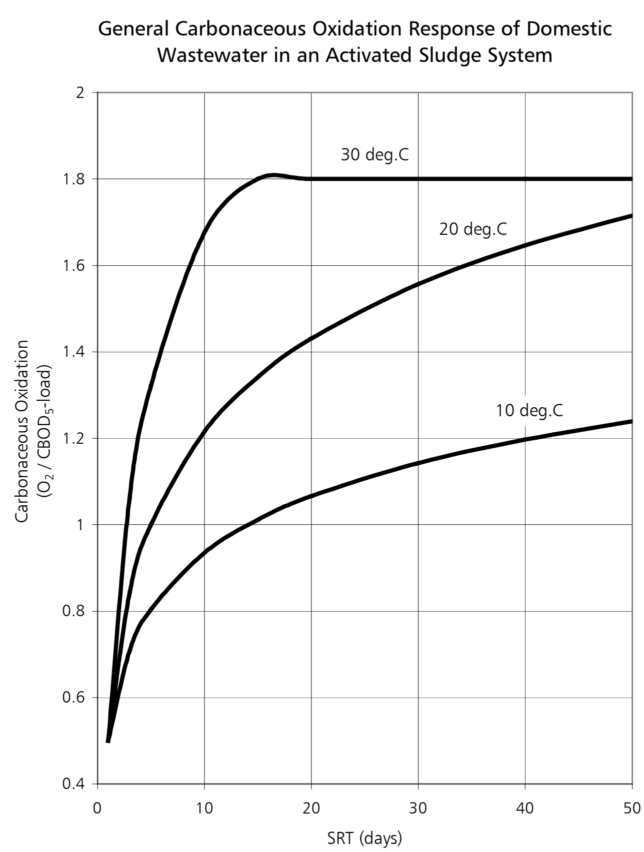
The oxidation of one pound of ammonia requires 4.3 to 4.6 pounds of oxygen. Typical domestic wastewater contains 25-30 mg/l of ammonia. Do not underestimate the oxygen demand to oxidize the ammonia. Oxidizing 25 mg/l of ammonia is equivalent to an additional 115 mg/l of BOD loading. Be award that even if a plant is not specifically designed to nitrify, that under favorable loading, temperature and SRT conditions, nitrification can and will occur. This may exert a large unanticipated oxygen demand on the system and may result in process failure. Figure 2 from the WPCF MOP 8 shows the relationship between SRT and nitrification efficiency.

3. SIDE STREAM LOADING

Good engineering design should analyze and account for side stream loads that are eventually returned to the aeration tanks. Generally, the most significant side stream loads will come from sludge handling or processing operations. Although the flows may be small, the BOD may be very high and result in significant oxygen demand applied to the aeration system. Some sources of side stream loading are:

- Septage receiving stations
- Filter press or vacuum filter filtrate and spray wash water
- Centrifuge centrate
- Effluent from dissolved air flotation thickeners
- Effluent from gravity thickeners
- Supernatant from aerobic or anaerobic digesters
- Filtrate from sand drying bed underdrains
- Wash water from grit dewatering screws
- Water from venturi scrubbers or cyclones
- Cooking liquors from thermal sludge processing operations
- Effluent from scum or grease processing equipment

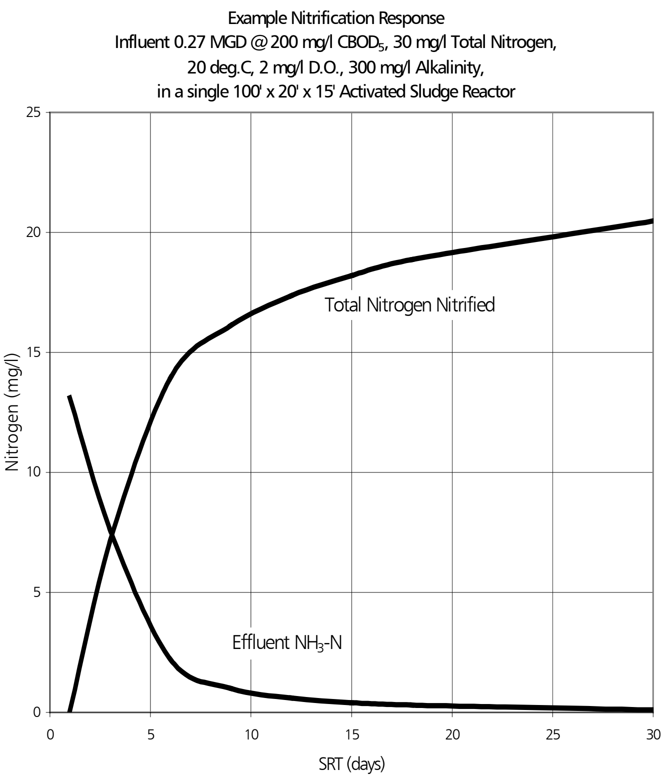
FIGURE 1



COMMENTARY

Responsible engineering design of an aeration system should include a rational determination of AOR taking into account BOD loading, ammonia loading, possible nitrification conditions and side stream loading. Further analysis of the oxygen demand and how it occurs spatially in time may result in minimum, average and peak values of AOR. Additionally, summer and winter operating conditions can also be different. Normal diurnal flow and loading patterns may be altered by factors such as sludge processing operations occurring in a single 8-hour work shift and should be factored into the design.

FIGURE 2



CALCULATING CONVERSION FROM ACTUAL TO STANDARD CONDITIONS: AOR/SOR RATIO

The preceding section described a rational method for determining AOR and some of the factors affecting it. AOR is a measure of the oxygen demand of the wastewater at specific site conditions. Conversion of AOR to SOR is affected by the following site conditions:

- Alpha
- Beta
- Site Elevation
- Dissolved Oxygen
- Temperature
- Saturation value for the device at the specified submergence

Altitude and temperature affect the amount of oxygen that can be dissolved or absorbed by the wastewater. More importantly, oxygen transfer in wastewater is different than in clear tap water. Wastewater also contains considerably more solids than tap water.

The general accepted formula to convert AOR to SOR is:

Equation 1

$$AOR = SOR(\alpha)\left[\frac{\left[\beta\left(\frac{P_f}{P_{MSL}}\right)C_{sat_T}\right] - \text{DO field}}{C_{sat_{20}}}\,\theta^{T-20}\right]$$

The terms in the formula are:

AOR = actual oxygen requirement (field conditions)

SOR = standard oxygen requirement (standard conditions)

Standard conditions are zero elevation (29.92 barometric pressure), 20° C and zero DO (dissolved oxygen in liquid).

$$\text{Alpha}(\alpha) = \frac{KL_a \text{ wastewater}}{KL_a \text{ tap water}}$$

Beta(β)	= Saturation Factor
P_f	= Barometric pressure at jobsite
P_{MSL}	= Barometric pressure at mean sea level
DO field	= Working dissolved oxygen concentration in wastewater
T	= Operating temperature of wastewater
C_{sat20}	= Surface DO saturation concentration at 20° C and standard conditions for the particular aeration equipment at the design submergence
C_{satT}	= Surface DO saturation concentration at design temperature T and 14.7 PSIA for the particular aeration equipment at the design submergence

COMMENTARY

Alpha – alpha is the ratio of the mass transfer coefficient in wastewater to the mass transfer coefficient in tap water. Alpha is the most variable factor in the formula and the most difficult to accurately test. Unfortunately, there is less known about alpha than any of the other terms in the formula. With the preceding in mind, the following generalizations can be made about factors that affect alpha values.

- BOD loading per unit volume
- Process used, i.e. a process that nitrifies typically less higher alpha values than a process that does not nitrify
- Type of aeration device, i.e. coarse bubble or fine bubble
- Mixing regime, i.e. plug flow or complete mix
- Location within aeration tank, influent end vs. effluent end
- Type of waste
- Submergence of aeration device

Sanitaire has conducted many in-waste oxygen transfer determinations on both coarse bubble and fine bubble systems in municipal and industrial wastewaters using off-gas methods. Off-gas testing can provide alpha values for a particular waste at the location tested. In complete mix tanks with fine bubble aeration, alpha values typically vary from about 0.4 to a high of about 0.7. Typically, alpha is in the range of 0.5 to 0.6 and these values can be used with a fair degree of certainty for domestic wastewater in the absence of testing. In plug flow type tanks with fine bubble aeration, alpha is generally lower at the inlet or influent and rises to the outlet or effluent end. Very narrow and very long (or multiple pass) aeration tanks seem to exhibit the greatest alpha gradient. Alpha values as low as 0.25 have been measured at the inlet of tanks with a large aspect ratio rising to approximately 0.9 at the outlet. Designers should be aware of the possibility of a significant alpha gradient in long narrow tanks.

In coarse bubble aeration tanks, alpha typically varies from about 0.6 to a high of about 0.95. Typically, alpha is in the range of 0.7 to 0.8 and these values can be used with a fair degree of certainty for domestic wastewater in the absence of testing. Coarse bubble alpha values as low as 0.5 have been measured in highly loaded complete mix paper mill waste. Alpha gradients can exist in coarse bubble aeration tanks but may be less than with fine bubble aeration due to the more turbulent mixing inherent with coarse bubble systems.

Beta – Beta is a saturation factor and is used to correct for the dissolved solids in wastewater. The solubility of oxygen in wastewater is approximately 95 to 99 percent of that of pure water. Beta is commonly accepted to be in the range of 0.95 to 0.99 unless dissolved solids are extremely high.

Theta – Theta is the correction factor for the temperature of the wastewater. Theta is commonly accepted to be 1.024 with the exponent T-20 power. Values of the expression θ^{T-20} are listed for temperatures of T = 10º C to T = 30º C. Note that at 20º C (68º F), the expression becomes θ to the zero power or 1.000. See Figure 3.

P_f – This is the barometric pressure at the jobsite in inches of mercury. See Figure 4.

P_{MSL} – This is the barometric pressure at mean sea level (standard conditions) and is 29.92 inches of mercury. The ratio P_f over P_{MSL} corrects for the reduced solubility of oxygen in water at higher altitudes.

DO $_{field}$ – This is the working dissolved oxygen concentration in the wastewater desired to be maintained. Typically, designers will pick a value of 2.0 mg/l at average conditions and often allow it to drop to 1.0 mg/l at peak conditions. The working dissolved oxygen concentration must be accounted for because it reduces the "driving force". The rate of oxygen transfer is dependent on the oxygen deficit. For example, if a particular device has the capability to saturate water to 10 mg/l as measured at the surface and 1 mg/l DO is maintained in the water; the deficit or driving force is 9 mg/l. If, on the other hand, 4 mg/l DO is maintained in the water, the driving force is only 6 mg/l.

T – T is the operating temperature of the wastewater in ºC. This correction must be made to account for the reduced solubility of oxygen in water at higher temperatures. Figure 5 shows the commonly accepted values for surface oxygen solubility at sea level for temperatures ranging from 0º C to 30º C. Note that this in not the C_{sat} value for the aeration device. Most diffused aeration devices have the ability to saturate the surface of the water and achieve higher values than those listed in Figure 5. Figure 6 shows the values of C_{sat} measured for both fine bubble and coarse bubble SANITAIRE diffusers at various submergences.

See the example problem at the bottom of Figure 5. Given that the C_{sat20} measured value for a particular device at a given submergence is 10.0 mg/l and the wastewater temperature is 30º C, find C_{sat30} measured. First, determine the ratio of surface C_{sa}(s) at sea level for 30º C and 20º C. From Figure 5, this ratio is 7.6 / 9.2. Multiply this ratio times C_{sat20} measured of 10.0 in this example to obtain 8.3 mg/l. This will be C_{sat30} measured for the particular device.

FIGURE 3

Temperature Correction Factor – Theta θ
Temperature Correction Expression θ^{T-20} and θ = 1.024

T (ºC)	Value of θ^{T-20}	T (ºF)
10	.0789	50.0
11	.808	51.8
12	.827	53.6
13	.847	55.4
14	.867	57.2
15	.888	59.0
16	.909	60.8
17	.931	62.6
18	.953	64.4
19	.977	66.2
20	1.00	68.0
21	1.024	69.8
22	1.049	71.6
23	1.074	73.4
24	1.100	75.2
25	1.126	77.0
26	1.153	78.8
27	1.181	80.6
28	1.209	82.4
29	1.238	84.2
30	1.268	86.0

FIGURE 4

Average Absolute Atmospheric Pressure

Altitude (Feet)	Inches of Mercury
-1000	31.00
-500	30.50
0	29.92
+500	29.39
1000	28.87
1500	28.33
2000	27.82
3000	26.81
4000	25.85
5000	24.90
6000	23.98
7000	23.10
8000	22.22
9000	21.39
10,000	20.58

FIGURE 5

Temperature Correction for C_{sat}

T (ºC)	Surface C_{sat} @ Sea Level
0	14.62
2	13.83
4	13.11
6	12.45
8	11.84
10	11.29
12	10.78
14	10.31
16	9.87
18	9.47
20	9.09
22	8.74
24	8.42
26	8.11
28	7.83
30	7.56

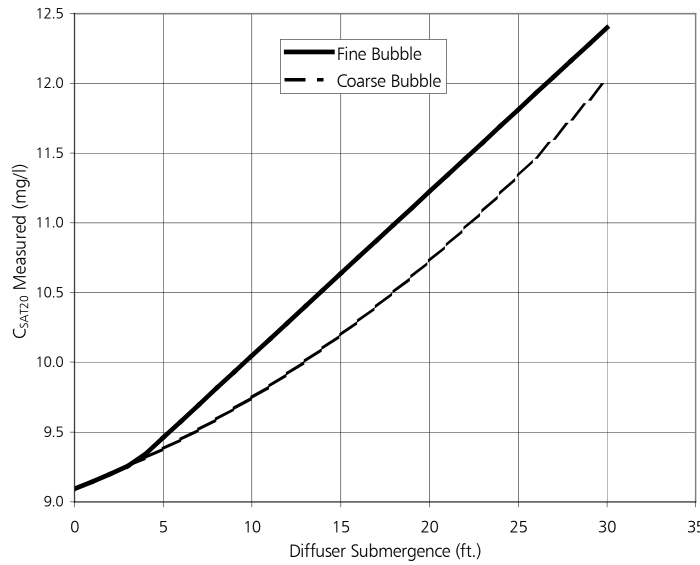
$$C_{satr} = C_{sat20} \text{ x } \frac{\text{Surface } C_{satr}}{\text{Surface } C_{sat20}}$$

Example: Given C_{sat20} = 10.0 mg/l
= 30º C

Find C_{sat30}

$$\text{Solution}: C_{sat30} = 10.0 \frac{(7.56)}{(9.09)} = 8.31 \text{ mg/l}$$

FIGURE 6



DETERMINING AIR REQUIREMENTS – APPROXIMATE ESTIMATES

Sanitaire has used a large aeration test tank facility to run thousands of individual oxygen transfer tests to determine the optimum performance of various aeration devices in a variety of geometric configurations and different water depths or submergences. This large database is used to develop computer-generated designs and to provide quick access for inquires on oxygen transfer. Due to the proprietary nature of the information, the performance curves are not made available to the general public. However, we are organized to respond quickly to engineers' requests for information on specific applications of these systems.

Engineers and designers often need quick, ballpark estimates of oxygen transfer efficiency and air requirements to check the viability of a proposed scheme or to approximate blower size and estimate horsepower requirements. The following are some quick "Rules of Thumb":

1. The typical AOR/SOR ratio for a COARSE BUBBLE aeration system is 0.50.
2. The typical AOR/SOR ratio for a FINE BUBBLE aeration system is 0.33.
3. The typical COARSE BUBBLE oxygen transfer efficiency is 0.75% per foot of diffuser submergence, i.e. 10 foot submergence equals 7.5% OTE in clear water.
4. The typical FINE BUBBLE oxygen transfer efficiency is 2.0% per foot of diffuser submergence, i.e. 10 foot submergence equals 20% OTE in clear water.
5. 1 SCFM of air weighs 0.075 pounds per cubic foot and contains 23% oxygen by weight. Therefore, 1 SCFM of air contains 0.0173 pounds of oxygen.
6. Approximate blower up = ___SCFM ___PSI at blower x .006

7. Annual power costs = \$325/yr/horsepower @ .05/kw power cost, \$520/yr/horsepower @ .08/kw power cost

Example:
Given an aeration tank with an AOR loading of 1500 pounds of oxygen per day, find the air volume required for a coarse bubble aeration system. Assume 15 foot deep tanks.

Solution:
1500 pounds per day O_2 AOR divided by 0.5 equals 3000 pounds per day O_2 SOR.

3000 pounds per day O_2 SOR divided by 1440 minutes per day equals 2.08 pounds per minute O_2 required. Locate diffusers 1 foot off tank floor or submergence equals 14 feet.

14 feet submergence times 0.75% OTE equals 10.5% OTE.

From Rules of Thumb #5, 1 SCFM contains 0.0173 pounds of O_2 and 10.5% is transferred to the waste, then 1 SCFM will transfer 0.0018 pounds of O_2 per minute.
Divide the demand of 2.08 pounds O_2 per minute by 0.0018 pounds of O_2 per minute transferred which equals 1156 SCFM required.

ESTIMATE BLOWER HORSEPOWER REQUIRED

The best source of specific information and horsepower requirements is the blower manufacturer. The following is provided as general information to enable the engineer or designer to make quick estimates of power requirements to check assumptions and compare alternative aeration systems. The easiest way to do this is to use the adiabatic compression formula and assume an overall mechanical efficiency for the blower, motor and coupling. The adiabatic compression formula is:

Equation 2

$$\mathrm{BHP} = \frac{\mathrm{SCFM}(.23)\left[\left(\frac{14.7+P}{14.7}\right)^{0.283} - 1.0\right]}{\text{MECHANICAL EFFICIENCY}}$$

Where BHP (brake horsepower) = $\dfrac{\text{adiabatic horsepower}}{\text{mechanical efficiency}}$

P = Blower discharge pressure in PSIG

A good estimate of the blower, motor and coupling mechanical efficiency is 70% when the blower is operating at mid-range. Efficiency will increase somewhat when the blower is operated at its maximum output and will decrease when operated closer to the surge point.

Figure 7 is a graph of blower horsepower per 1000 SCFM at various discharge pressures assuming 60%, 70% and 80% mechanical efficiency. Figure 8 is a schematic diagram of an aeration system in a 15 foot deep tank with the diffusers at 13 feet submergence. Note that the static submergence of 13 feet (5.64 PSI) is not the blower discharge pressure. In the example, filter and inlet losses plus air main piping losses plus friction losses in the aeration equipment need to be summed to equal a total of 6.47 PSIG blower discharge pressure.

FIGURE 7

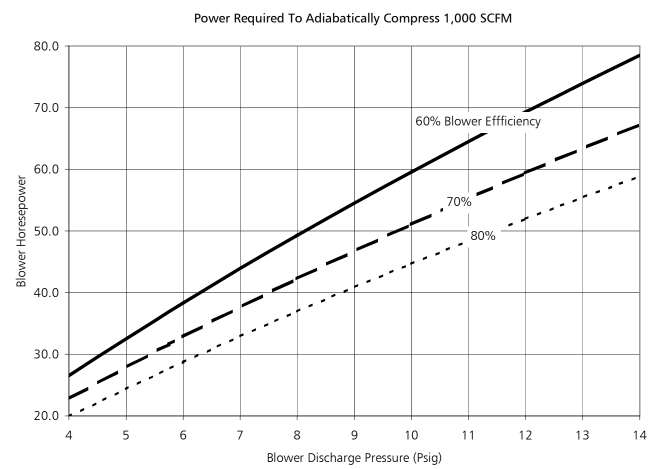
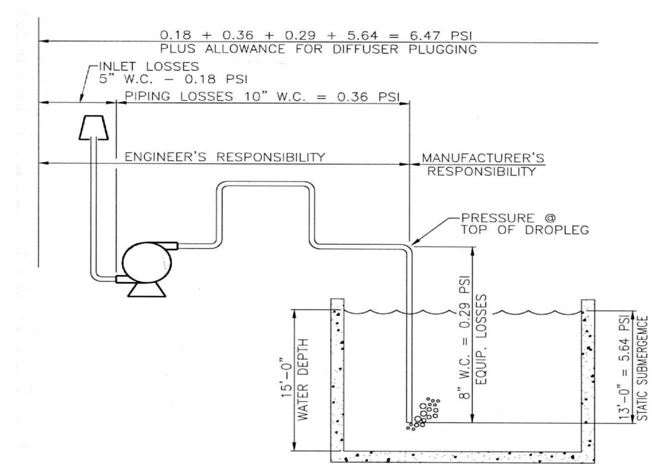


FIGURE 8



TYPICAL 1 MGD AERATION TANK DESIGN EXAMPLE
The following example and calculations will present a simplified approach to aeration tank design and present several different coarse bubble and fine bubble equipment configurations for illustrative purposes.

GIVEN:

1. Average daily flow is 1 MGD
2. Loading is domestic and industrial sewage containing 200 mg/l BOD, 250 mg/l SS and 30 mg/l NH_3N
3. Plant will use primary clarifiers preceding aeration
4. Side stream loading to be returned to the aeration tanks consists mainly of aerobic digester supernatant, sludge

filter press filtrate and wash water. Total side stream contribution is expected to be 50,000 GPD containing 2000 mg/l BOD.

5. Review of past flow and loading characteristics reveal the following:
   The major industrial contributor to the wastewater plant has periodic process shutdowns during weekends, extended holidays and completely closes for two weeks in the summer for employee vacations. During this period, the organic loading to the plant drops to 75% of the average day loading.
6. Winter wastewater temperature is anticipated to be 15° C and summer temperature is anticipated to be 20° C.
7. The plant is required to nitrify year-round to 0.1 mg/l NH_3N allowable in effluent. BOD and SS requirements are 5.5 year-round.
8. Site elevation is 5000 feet above sea level
9. Desired aeration tank DO level is 2.0 mg/l at all conditions
10. 1.0 pounds of oxygen per pound of BOD applied and 4.6 pounds of oxygen per pound of ammonia applied will be used for the calculations
11. A standard rate activated sludge process has been selected and will be designed using 35 pounds of BOD applied per 1000 cubic feet of aeration tank volume.
12. Aeration tank geometry is to be conventional, 1 pass, 30 feet wide and 15 feet liquid depth with diffuser submergence of 14 feet.
13. Coarse bubble alpha is assumed to be 0.75 and fine bubble alpha is assumed 0.50. Beta in both cases will be assumed to be 0.95.

CALCULATE:

1. AOR
2. Aeration tank size
3. Air requirements
4. Actual coarse bubble and fine bubble AOR/SOR ratios

SOLUTION:

1. Calculate AOR:

From the list of givens, we will assume 30% BOD removal in the primary clarifiers. The influent BOD loading to aeration is then:

70% x 200 mg/l x 8.33 lbs. mg/l/MGD x 1 MGD
= 1166 lbs. BOD

The side stream BOD loading to aeration is then:

2000 mg/l x 8.33 lbs./mg/l/MGD x 0.05 MGD
= 833 lbs. BOD

Total lbs. BOD to aeration is 1999 or approximately 2000 lbs.

Ignore the BOD in the effluent and assume all 2000 lbs. BOD must be oxidized in aeration tanks as an additional factor of safety. We have previously determined that we will use 1.0 pounds of oxygen per pound of BOD applied. Therefore, the average AOR for BOD is 2000 pounds of oxygen. In addition, from the list of givens, we know that the minimum loading will be 75% of the average and peak loading will be 150% of the average.

We now have:

Minimum day BOD AOR = 1500 lbs. O_2
Average day BOD AOR = 2000 lbs. O_2
Peak day BOD AOR = 3000 lbs. O_2

The influent ammonia loading to aeration is then:

30 mg/l x 8.33 lbs./mg/l/MGD x 1 MGD
= 250 lbs. ammonia

Ignore the ammonia in the effluent. We have previously determined that 4.6 pounds of oxygen per pound of ammonia applied is required or 1150 pounds of oxygen. In addition, from our givens, the minimum loading will be 75% of the average and there is no peak ammonia loading.
We now have:

Minimum day NH_3N AOR = 863 lbs. O_2
Average day NH_3N AOR = 1150 lbs. O_2
Peak day NH_3N AOR = 1150 lbs. O_2

Combining the AOR numbers for BOD and NH_3N yields the following oxygen requirements:

Minimum day AOR = 2363 lbs. O_2
Average day AOR= 3150 lbs. O_2
Peak day AOR = 4150 lbs. O_2

Remember that we have also defined a summer and winter temperature range of 20° C and 15° C respectively.

2. SIZE AERATION TANK

We have previously determined the process is the standard rate activated sludge process loaded at 35 pounds of BOD per 1000 cubic feet (KCF) of tank volume. Then 2000 lbs. BOD/day divided by 35 lbs./KCF equals 57.14 KCF tank volume (57,140 ft^3).

The tank cross sectional area is 30 feet wide x 15 feet deep or 450 ft^3 area. Then 57,140 ft^3 divided by 450 ft^2 = 127 feet long.

The aeration tank dimensions are then 30 ft. x 15 ft. SWD by 127 feet long.

With the preceding information you are now in a position to request product equipment information from an equipment manufacturer or proceed on your own using the rules of thumb for a ballpark estimate.

3. CALCULATE AIR REQUIREMENTS

Rule of Thumb Method – Coarse Bubble

Average day AOR = 3150 lbs. O_2
Typical coarse bubble AOR/SOR ratio = 0.50
Therefore, SOR = 6300 lbs. O_2/day
= 4.375 lbs.

O_2/min.
Submergence is 14 ft. OTE = 14 ft.
14 ft. x 0.75% per ft. = 10.5% OTE
1 SCFM contains 0.0173 lbs. O_2
At 10.5% OTE, 1 SCFM will transfer 0.00182 lbs. O_2/min.
4.375 lbs. O_2/min. ÷ .00182 lbs. O_2/min/SCFM
= 2404 SCFM required

Rule of Thumb Method – Fine Bubble

Average day AOR = 3150 lbs. O_2
Typical fine bubble AOR/SOR ratio = 0.33
Therefore, SOR = 9545 lbs. O_2/day
= 6.628 lbs. O_2/min
Submergence is 14.33 ft.
OTE = = 14.33 ft.
14.33 ft. x 2.0% per ft. = 28.66% OTE
1 SCFM contains 0.0173 pounds O_2
At 28.66% OTE, 1 SCFM will transfer 0.00496 lbs. O_2/min
6.628 lbs. O_2/min ÷ 0.00496 lbs. O_2/min/SCFM
= 1336 SCFM required

4. CALCULATE COARSE BUBBLE AND FINE BUBBLE AOR/SOR RATIOS

The actual AOR/SOR ratios determined by using equation #1 for the given conditions are:

Equipment	Temperature	AOR/SOR Ratio
Coarse Bubble	15° C	0.460
	20° C	0.448
Fine Bubble	15° C	0.310
	20° C	0.303

COMPUTERIZED DESIGN EXAMPLES

As previously stated, Sanitaire has computerized design capabilities to quickly generate product application information. Six possible equipment configurations were computed for the 1 MGD Design Example. Four of the configurations are for coarse bubble aeration equipment and two of the configurations are for fine bubble equipment. The examples were selected to show the geometry on oxygen transfer, initial equipment cost, annual operating costs and amortized capital costs.

COARSE BUBBLE
Example No. 1 uses a fixed header located at the side of the tank. OTE is 9.17%, air required for summer average conditions is 3058 SCFM and blower horsepower required is 126.77. The installed cost of the equipment is estimated to be $27,000

Example No. 2 moves the same header to the center of the tank. OTE is 10.39%, air required is 2702 SCFM and blower horsepower is 112.05. Installed cost of the equipment is the same, $27,000.
Example No. 3 uses dual fixed headers located at the quarter points. OTE is 12.22%, air required is 2297 SCFM and blower horsepower is 94.96. Installed cost of the equipment is $30,000.

Example No. 4 uses 3 fixed headers in the tank. OTE is 13.15 %, air required is 2134 SCFM and blower horsepower is 88.37. Installed cost of the equipment is $39,500.
The pertinent information from the computer output is summarized in Figure 12.

COMMENTARY (COARSE BUBBLE)

The preceding examples show that a more uniform distribution of air applied over the tank width increases OTE, therefore reducing the process air volume required. The reduction in airflow results in power savings. Moving the fixed header from the sidewall to the center of the tank results in a 11% savings in air volume at no increased cost.

Replacing the single center placed header with two smaller headers results in a 15% savings in air volume at a very slight increased cost.

Replacing the dual headers with 3 headers achieves another 2% savings in air volume, but the cost rises significantly.
The comparison is best shown in Figure 10, Coarse Bubble Geometry Effect which plots cumulative owning and operating costs versus operating years. This analysis

Figure 9 Coarse Bubble Design Summary
Data from Computer Printouts Based on Summer Average Conditions

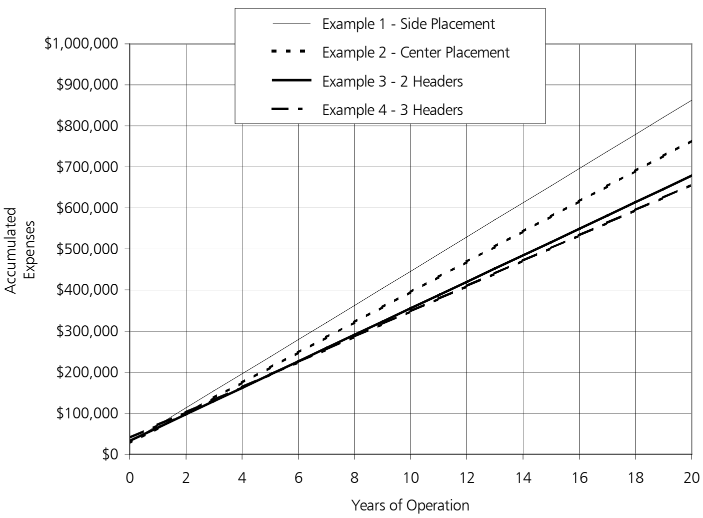
Item	Example 1 Side Placement	Example 2 Center Placement	Example 3 2 Headers	Example 4 3 Headers
OTEcw%	9.18	10.3	12.2	12.5
OTEf%	4.11	4.61	5.47	5.6
SCFM	3149	2702	2297	2233
PSIG Top of Tank	6.3	6.3	6. 3	6.4
PSIG of Blower	6.6	6.6	6.6	6.6
Blower HP	127.4	112.7	95.8	94.3
Annual Power Cost 1	$41,400	$36,700	$31,100	$30,650
Equip Cost 2	$27,000	$24,600	$30,000	$36,400
Installed Cost 2	$29,700	$27,000	$33,000	$40,000
Amortized Cost 3	$3026	$2,751	$3363	$4,076
Total Annual Cost 4	$44,426	$39,451	$34,463	$34,726

1- Based on $0.05 per kWh
2- Based on 1999 costs
3- 20 year life, 8% interest, Crf = 0.1019
4- Includes annual power cost and amortized cost

assumes $0.05 per kWh constant power cost and a capital recovery factor (Crf) equal to 0.1019. This assumes a 20-year payback at 8% interest on the installed equipment cost. When viewed in this manner, clearly the two header system is very cost effective, saving almost $200,000 in 20 years for an additional $3000 first cost investment. The three header system saves $450 in power costs over the two header system in 20 years, but requires $6400 more first cost investment. Based on 20-year life, the 2 header option yields the lowest total annual cost. If the life cycle is reduced or power costs change, this may not be the best option.

The preceding analysis does not account for any savings in first cost of smaller blower and motors required. A more rigorous analysis may show greater savings.

FIGURE 10



FINE BUBBLE EXAMPLES
EXAMPLE No. 5 uses a 5% density (AT/AD = 20) or porous ceramic diffusers on the tank floor. This would be 460-9 inch units. OTE is 23.7%, air required is 1747 SCFM and blower horsepower required is 82.2. The installed cost of the equipment is estimated to be $25,000.

Example No. 6 uses a 10% density (AT/AD = 10) of porous ceramic diffusers on the tank floor. This would be 928 – 9 inch units. OTE summer average is 28.5%, air required is 1456 SCFM and blower horsepower required is 63.1. The installed cost of the equipment is $31,500. A summary follows in Figure 11.

FIGURE 11

FINE BUBBLE DESIGN SUMMARY
Data from Computer Printouts Based on Summer Average Conditions

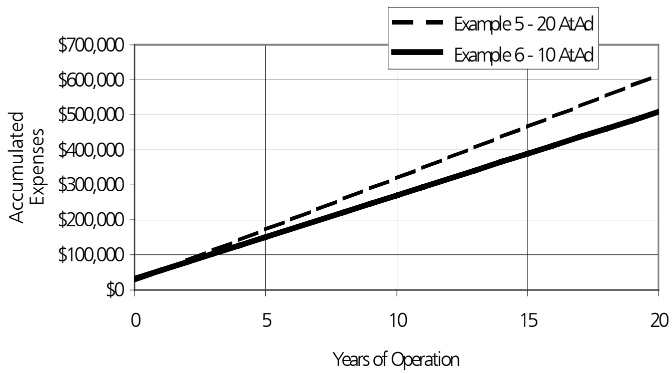
Item	Example 5 AT/AD = 20 5% Diffuser Density	Example 6 AT/AD = 10 10% Diffuser Density
OTEcw%	23.7	28.5
OTEf%	7.17	8.60
SCFM	1747	1456
PSIG at Top of Drop	7.45	6.6
PSIG at Blower	7.3	6.9
Blower HP	82.2	63.1
Annual Power Cost 1	$26,715	$20,508
Equip Cost 2	$20,000	$25,200
Installed Cost	$25,000	$31,500
Amortized Cost 3	$2,547	$3,210
Total Annual Cost 4	$29,262	$23,718

1- Based on $0.05 kWh
2- Based on 1999 costs
3- 20 year life, 8% interest, Crf = 0.1019
4- Includes annual power cost and amortized cost

COMMENTARY (FINE BUBBLE)
These examples show that an increased diffuser density and lower air rates per diffuser increase. The increased OTE will lower air and power requirements. This comparison is shown in Figure 12, Fine Bubble Geometry Effect. This analysis also assumes $0.05 per kWh constant power cost a capital recovery factor (Crf) equal to 0.1019, which is 20 years at 8% interest. The 10% density option saves $110,880 over 20 years for an additional $6500 first cost investment.

Also, note, in comparing Figures 10 and 12, that least effective fine bubble option shows a 20 year owning and operating cost slightly better than the most efficient 3 header coarse bubble option.

Figure 12



The nomenclature AT/AD is an expression Sanitaire uses to define the density of porous ceramic diffusers. It means Area of Tank Floor divided by Area of Diffusers. Both terms use square feet as units of measure and the area is measured as horizontal projected area. The area of the SANITAIRE 9" diameter ceramic diffuser is 0.41 ft^2 and the area of the SANITAIRE 7" diameter diffuser is 0.28 ft^2. A larger AT/AD number means less density. For example:

AT/AD	% of Tank Floor Covered with Diffusers
20	5.00%
16	6.25
12	8.33
10	10.00
8	12.50
6	16.67
4	25.00

Increasing diffuser density may reach a point of diminishing return. Loadings, power costs, tank configuration, etc affect this.

The practical ranges of diffuser densities are from 4.5 to 20. Densities below 4.5 are not practical due to space considerations; it is physically not possible to have more diffusers than this on the tank floor and still have room to step between diffusers and distributors. To achieve an AT/AD value of 4.5 with the 9" units requires spacing the diffusers at 13" centers (minimum spacing) on the distributors and spacing the 4" distributors at 18" centers. This leaves only 8" clear between edges of diffusers in which to step. On the other hand, densities greater than 20 may not adequately mix the mixed liquor and keep it suspended. To achieve an AT/AD value of 20 with the 9" units requires spacing the diffusers at 30" centers on the distributors and spacing the 4" distributors at 42" centers. This density requires running the diffusers at 1SCFM per unit just to achieve 0.12 SCFM per square foot of tank floor area which is generally accepted to be the minimum desirable air rate to keep mixed liquor solids suspended with fine bubble aeration.

REFERENCES

1. "Recommended Standards for Sewage Works", Great Lakes – Upper Mississippi River Board of State Sanitary Engineers, 1978.
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3. "Activated Sludge Manual of Practice No. OM-9", Water Pollution Control Federation, 1987.
4. "A Standard for the Measurement of Oxygen Transfer in Clean Water", American Society of Civil Engineers, 1984.
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6. "Aeration Manual of Practice No. FD-13", Water Pollution Control Federation, 1988.
7. "Design Manual Fine Pore Aeration Systems", US EPA, EPA/625/1-89/023, 1989.