

GAS TRANSFER

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Recirculating Aquaculture Systems Short Course

The availability of dissolved oxygen (DO) is usually the first factor that limits increased carrying capacity and production in intensive recirculation systems. Using only aeration as a means of providing dissolved oxygen, a system can support only about 40 kg per m³ (0.33 lb of fish per gallon) of water. However, by using pure oxygen and high efficient gas transfer devices to increase the amount of dissolved oxygen in the water column, stocking densities can easily be increased to over 120 kg per m³ (1 lb of fish per gallon) of water. For example, by increasing the DO concentration at the inlet to a production tank from 10 mg/L (aeration alone) to 18 mg/L using pure oxygen, and assuming a DO concentration of 6 mg/L at the discharge, the carrying capacity of the system can be increased by a factor of three. Instead of only 4 mg/L DO (10 mg/L minus 6 mg/L) being available for respiration and metabolism by the fish, 12 mg/L becomes available (18mg/L minus 6 mg/L). Thus stocking densities can be increased from 0.33 lb/gal (40 kg/m³) to 1.0 lb/gal (120 kg/m³). An interesting by-product of this increased stocking density is that the concentration of the discharged solids is also increased, which means more efficient removal by, for example, microscreen filters.

In an aquaculture system operating at these high stocking densities, with low water exchange rates, oxygenation with little aeration and low pH, it is probable that dissolved carbon dioxide, a product of fish respiration, will accumulate to levels that create toxic conditions for both the fish and the biofiltration system. Other dissolved gases that also can be important to system operation are nitrogen, argon, and hydrogen sulfide, and in some special circumstances, methane, ammonia, and radon. In considering a treatment approach, it is important to understand that modification of the concentration of a particular gas, such as oxygen, may significantly change the concentration of other gases in solution. Thus, the design of a gas transfer system must take into consideration all the potential impacts of all the dissolved gases, as well as such water quality parameters as alkalinity, hardness, pH, and concentrations of iron and magnesium.

Dissolved Gases - Fundamentals

Dry Air Components

Species	% volume	% mass	Molecular Wt.
Nitrogen	78.084	75.600	28.0
Oxygen	20.946	23.200	32.0
CO ₂	0.032	0.048	44.0
Argon	0.934	1.300	39.9
Air	100.000	100.000	29.0

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The atmosphere is composed of 20.946% oxygen (O₂), 78.084% nitrogen (N₂), 0.934% argon (Ar), 0.032%, carbon dioxide (CO₂) and other trace gases, see table above. Barometric pressure (BP), or atmospheric pressure, is the sum of the partial pressures exerted by each of the individual gases in the atmosphere. The partial pressure of each gas is directly proportional to the mole fraction of that gas. Thus for oxygen at a standard temperature and pressure (STP) of 760 mm of Hg, its partial pressure is 760 mm times 0.20946 or about 160 mm Hg. Gauge pressure is equal to total pressure minus atmospheric pressure. In water, the Total Gas Pressure (TGP) is the sum of all partial gas pressures contributed by the individual gases, and can be greater than or less than barometric pressure. If the ratio of the Total Gas Pressure to barometric pressure is greater than one, the water is considered to be supersaturated. This is not good!

Dissolved Gases - Fundamentals

The solubility of a gas (mg/L)

Gas Species	Solubility in Air* (mg/L)	Solubility of pure gas* (mg/L)
Oxygen	10.08	48.14
Nitrogen	16.36	20.95
Argon	0.62	65.94
Carbon dioxide	0.69	1992.00
*At 15 Deg. C.		

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The solubility of a gas (mg/L) in water depends on its temperature, salinity, gas composition, and total pressure. The solubility of the four major gases is presented above as a function of gas composition.

From the Table above, it can be seen that by increasing the mole fraction of oxygen from 0.20946 in air to 1.0000 with pure oxygen, the solubility or concentration of oxygen is increased from 10.08 mg/L to 48.14 mg/L (at 15°C).

The solubility of a gas is also proportional to its absolute pressure. Increasing the gas pressure will also increase gas solubility proportionately, i.e., doubling the gas pressure will double that gases solubility. Higher gas pressures occur in water injected into a pressurized system, or in water obtained from a deep well. One problem when using air as the oxygen source is that increasing the air pressure will also increase the solubility of nitrogen and argon above normal air saturation concentrations, which can result in potential gas supersaturation problems. Total gas pressure (TGP) for most systems should generally be kept below 105%, although the actual value is dependent on species and life stage.

Note that the percentage makeup of the air will not change with elevation (up to 90 km), but the total pressure will change as noted above. In addition, assuming 100% humidity conditions will change the above numbers; water vapor pressure will be approximately 10 to 15 mm Hg and is temperature dependent.

Gas Solubility Equations

The solubility of a gas (mg/L)
is determined using Henry's Law

$$C_{s,i} = 1000K_i\beta_iX_i \frac{P_{BP} - P_{wv}}{760}$$

β_i = Bunsen Coefficient for gas species "i", L/L-atm
 X_i = Mole fraction of gas (dimensionless)
 P_{BP} = Barometric pressure, mm Hg
 P_{wv} = Water vapor pressure, mm Hg

Solubility (gas) Coefficient =
ml's gas per ml's liquid (water)

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Saturation levels for dissolved oxygen, nitrogen, and carbon dioxide ($C_{s,i}$) were calculated as a function of temperature and pressure based on Henry's Law (Colt, 1984):

$$C_{s,i} = 1000 * K_i * \beta_i * X_i [P_{BP} - P_{wv}] / 760$$

β_i = Bunsen Coefficient for gas species "i", L/L-atm
 X_i = Mole fraction of gas (dimensionless)
 P_{BP} = Barometric pressure, mm Hg
 P_{wv} = Water vapor pressure, mm Hg

The Bunsen coefficients () and the water vapor pressure (P_{wv}) used in this determination were obtained from relationships developed by Weiss (1970, 1974) and ASHRAE (1972). The Bunsen coefficients are calculated separately for oxygen, nitrogen, and carbon dioxide and are included in the text. It is important to note that these coefficients are a function of temperature.

What is important about the above equation, is that the solubility of a gas is directly dependent upon the mole fraction of gas, the barometric pressure, the temperature through the Bunsen Coefficient and water vapor pressure. Thus to increase the solubility of any gas, any one of these parameters can be altered. For example the barometric pressure can be increased by pressurizing the gas transfer device, the temperature can be altered, or as usually is the case the mole fraction can be changed by using pure oxygen instead of air.

Thus when gas concentrations are NOT 100% of a particular gas, then the dissolved gas concentration becomes proportional to the % gas composition present:

$$C_x (\%) = [C_{100\%}] \cdot [\% \text{ concentration of gas species } x]$$

As mentioned above, equilibrium conditions can also be proportionately altered by changing the Total Pressure of the gas and maintaining the same % concentrations. For example, U-Tubes increase potential dissolved oxygen levels at the bottom of the U-Tube proportionate to the depth of the U-Tube. Similar changes in dissolved equilibrium concentrations can be caused by manipulating pressure or gas concentration.

Gas Transfer

Gas Transfer Occurs Due to Pressure Differences

$$Q_x \text{ (mass/time)} = (1/R) (P_{i,\text{high}} - P_{i,\text{low}})$$

where

- Q = rate of gas flow of species x
- P = pressure
- X = gas species
- R = Resistance to flow (design related)

Design and Operation will influence
RESISTANCE to gas transfer

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Gas Transfer is proportional to pressure difference for each particular gas. A species gas will move into a “higher” total pressure environment if the partial pressure of the species gas is higher than the species gas pressure in the “other” environment. Design and operational methods will influence and control *resistance* to gas transfer. Partial Pressure Differences determine *potential* for equilibrium dissolved gas conditions.

Principle: Gas transfer occurs due to pressure differences.

The rate of gas flow from a high pressure area to a lower pressure area is determined by the *resistance* to gas flow from the high to low pressure areas.

$$P(h) = \frac{760}{[760 + (\frac{h}{32.8})]} \cdot 760$$

Values for Pressure

- Atmospheric Pressure
 - Sea Level
 - 760 mm Hg (mercury)
 - 34 feet of water column
 - 14.96 psi
- Correcting for Elevation

$$P(h) = \frac{760}{[760 + (\frac{h}{32.8})]} \cdot 760$$

h is feet (not meters) of elevation above sea level

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Atmospheric Pressure

At sea level

- 760 mm (29.91 inches) of mercury (Hg)
- 34 feet of water column
- 14.96 psi

Correcting for elevation. See above equation.

Terms Used to Describe Pressure

Total Gas Pressure = SUM of all Partial Pressures

where: Partial Pressure = pressure contribution of an “individual gas”

Gauge Pressure = Total Pressure – Atmospheric Pressure

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Finally, of particular importance to fish culture is the total gas pressure (P_{TG}) of the combined gases in solution:

$$P_{TG} = P_{oxygen} + P_{nitrogen} + P_{CO2} + P_{wv}$$

We often have fish culture recommendations based around an acceptable P_{TG} expressed as a percentage value:

$$P_{TG} (\%) = [P_{TG} / P_{BP}] * 100$$

Atmospheric Pressure is a sum of the **partial pressures** of contributing gases. **Total gas pressure (TGP)** is also sum of all the partial pressures (there may be non-typical gas concentrations for an individual gas component). Total Gas Pressure should not exceed 105% of atmospheric pressure (species dependent). Pure oxygen systems and green water systems can be subject to excessive total gas pressure problems. Incomplete degasification of “incoming” water, particularly for nitrogen, can lead to excessive total gas pressure (causes gas bubble disease in fish), since incoming water sources often are supersaturated with nitrogen gas.

Gauge pressure is:

$$\text{Gauge Pressure} = \text{Total Pressure} - \text{Atmospheric Pressure}$$

Fundamentals of Gas Transfer

Two factors that directly impact the rate of gas transfer:

- the area of gas-liquid interface
- the difference between the concentration (partial pressure) at saturation and the existing concentration of the gas in the water.

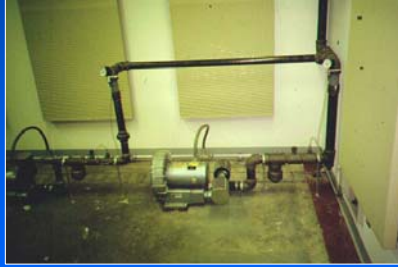
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When air is in contact with water, dissolved gases in the water attempt to reach equilibrium with the partial pressures of the gases in the atmosphere. Two factors that directly impact the rate of gas transfer are first the area of gas-liquid interface and second the difference between the concentration (partial pressure) at saturation and the existing concentration of the gas in the water. For example, if the water is under saturated with the gas in question (a deficit), the gas will be transferred into solution and if the water is supersaturated, out of solution. In a simple trickling tower, it is possible to have supersaturated nitrogen gas being removed, while under saturated dissolved oxygen, increases in concentration. This overall gas transfer rate is dependent on the deficit (or surplus) of a dissolved gas and a proportionality constant, usually called the gas transfer coefficient. The overall gas transfer coefficient represents conditions in a specific gas transfer system. It is a composite term that includes such factors as the diffusion coefficient for the gas, the liquid-film thickness, and the area of gas-liquid interface. These factors also suggest ways to increase the overall rate of gas transfer. This could be accomplished, for example, by decreasing the liquid-film thickness by turbulence or mixing, increasing the gas-liquid interface by making the bubble size smaller, or increasing the concentration gradient.

Gas Transfer Options

Aeration Systems – Air Stones, Packed Towers

Sources of Air



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Aeration Systems – Air Stones, Packed Towers

Sources of Air

The standard sources of air in aquaculture are blowers, air pumps, or compressors. The primary differences between them are the pressure requirements and the volume of the discharge. Blowers supply high volumes of air at low pressure, while compressors supply small volumes of high pressure air. In specifying the type of air source required, two design parameters need to be determined: the required pressure and the required air volume. The operating pressure is determined by the requirements to overcome the water pressure at the diffuser's depth, the pipe friction losses, and the diffuser's resistance to air flows. For a typical application of air stones in a shallow (1 m or 3 ft) tank, this is about 2 to 3 psi (125 mm Hg). In deeper tanks or with diffusers requiring higher pressures, i.e., those with smaller bubbles or clogged pores, this could be considerably higher. The air volume required is determined by the pounds of oxygen required and the overall transfer efficiency of the system. For example, a 9 inch (23 cm) air stone operating in 3 feet (1 m) of water with 0.7 cfm (1.2 m³/h) air supply transfers only 0.023 lbs/hr (0.25 kg/day) of oxygen.

Regenerative blowers are designed to provide large volumes of air at low pressure, typically less than 4 psi (190 mm Hg). They are most commonly used with either air stones or airlift systems. Advantages of regenerative blowers include their low noise levels, reliability, energy efficient motors, and lower comparative cost. Air pumps operate in the mid-range of performance, between blowers and compressors. Compressors are designed for high pressure operations, such as in very deep tanks or where long airlines are required.

Gas Transfer Options

Air stones: very inefficient O₂ transfer devices (3 – 7%)



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Air stones

Air stones are very inefficient oxygen transfer devices (3–7%), but very inexpensive in terms of capital and operating costs. At low stocking densities and high exchange rates, they work very well at maintaining adequate oxygen levels. One disadvantage is the maintenance requirements due to clogging and biofouling, especially in very hard water.

Gas Transfer Options

Oxygen Transfer Systems

Sources of Oxygen



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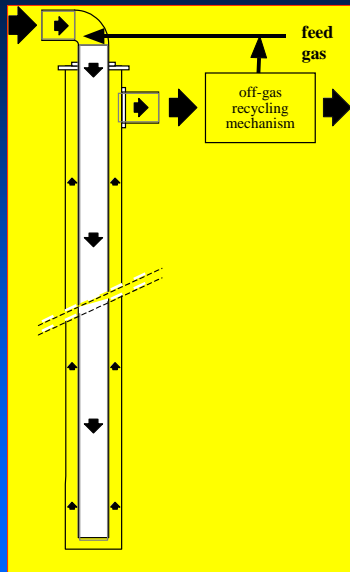
Sources of Oxygen

In aquaculture, three sources of oxygen are commonly used: high-pressure oxygen gas, liquid oxygen (LOX), and on-site oxygen generations. To insure availability and as backup, usually at least two sources are available at most facilities. High pressure oxygen gas is easily available in cylinders containing from 100 to 250 ft³ (3 to 7 m³) of gas at 2550 psi (170 atmospheres of pressure). A number of cylinders can be connected together using commercially available manifolds to increase the total capacity. Due to their cost and limited capacity, oxygen cylinders are normally used only as emergency backup systems.

In many areas, liquid oxygen is commercially available in bulk and can readily be transported and stored in on-site Dewar's type storage containers. At one atmosphere, liquid oxygen boils at -297.3°F (-182.96°C), thus special insulated cryogenic containers are required for storage. These containers range in size from 30 gal (0.11 m³ liquid) to a much as 10,000 gal (38 m³ liquid), and are usually rented or leased from the suppliers, although the smaller units can be purchased. One gallon of liquid oxygen is equal to 115 ft³ (3.26 m³) of gaseous oxygen. The maximum gas pressure in these containers is in the range of 150 to 200 psi (11.7 atmospheres). Prior to its use, the LOX is vaporized by directing it through heat exchanger coils. A liquid oxygen supply system will consist of a storage tank, vaporizer, filters, and pressure regulators. The economics of LOX use are dependent upon the transport cost, and the reduced capital and maintenance cost as compared to pressure swing adsorption (PSA) systems. In general, a LOX system is very reliable, operating even during power failures. Failures on farms using LOX systems as backup to power outage are caused by under-sizing the LOX system in the first place or unanticipated severe weather conditions that extend longer than predicted. Carefully consider your risks for such cases and size your LOX system with these potential dangers in mind. As a minimum, a LOX system should be able to maintain a facility with oxygen for 30 days. Remember that upon the first sign of major weather problems, it is probably prudent to take your fish off of feed, which will lower their oxygen demand dramatically over the next 24 hours.

Oxygen can also be generated on-site using either a pressure swing adsorption (PSA) or a vacuum swing adsorption (VSA) unit. In both cases, a molecular sieve material is used to selectively adsorb or absorb nitrogen from the air, producing an oxygen-enriched gas. Commercially available units can produce anywhere from 1 to 30 lbs (0.5 to 14 kg) of oxygen per hour at from 10 to 50 psi (0.7 to 3.3 atmospheres). A source of dry, filtered air at 90 to 150 psi (6.0 to 10.0 atmosphere) is required to produce an oxygen stream that is from 85–95% pure. PSA and VSA units operate on a demand basis and produce oxygen only when needed. They have proven to be very reliable and require little maintenance. However, they are both expensive in terms of capital and operationally expensive, due to the compressed air requirements. Also, since they require electrical power, some other source of oxygen is needed in the event of power failures or else the facility must be equipped with large backup generators and transfer switches.

Gas Transfer Options



U-tubes

"Rule of Thumb" U-Tube Aerator

- Design U-Tubes for a down flow velocity between 2 m/s to 3 m/s
- Limit G/L ratio to <25%

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U-tubes

The U-tube aerator operates by increasing the gas pressure, thus increasing the overall gas transfer rate. It consists of either two concentric pipes or two pipes in a vertical shaft 30 to 150 ft (9 to 45 m) deep. Oxygen is added at the upper end of the down-leg of the U-tube and as the water/gas moves downward through the contact loop, an increase in hydrostatic pressure increases the oxygen transfer rate. The overall oxygen transfer efficiency is a function of the depth of the U-tube, inlet gas flow rate, water velocity, diffuser depth and inlet DO concentration. Concentrations of dissolved oxygen ranging from 20–40 mg/L can be achieved, but the overall oxygen transfer efficiency is only 30–50%. Off-gas recycling can improve the absorption efficiency to 55–80%. Two advantages of the U-tube are the low hydraulic head requirements that allow operation with no external power if sufficient head is available, and that it can be used with water containing high levels of particulates or organics. Its chief disadvantages are that it does not vent off gasses such as nitrogen or carbon dioxide very efficiently and construction costs can be high, particularly if bedrock is present.

U-tubes are designed for flows where the downflow velocity is between 1.8 to 3.0 m/s. A particularly unique problem with U-tubes is that if too much oxygen is added a gas bubble blockage can occur that results in flow interruption. This will tend to happen if gas-liquid ratios exceed 25%. Be careful when adding oxygen.

Gas Transfer Options

Packed Columns

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Packed Columns

Packed columns consist of a vertical column filled with media having a high specific surface area. Water is uniformly distributed over the top of the media with a perforated plate or through a spray bar, and trickles down through the media. Oxygen is injected into the column and is transferred into the passing water through the large gas/liquid interface on the media. The column may be either open or closed at the top. Packed columns are efficient nitrogen strippers, but require a higher gas/liquid ratio (forced aeration) for carbon dioxide stripping. Packed columns are simple to build and easy to retrofit into existing facilities. Performance design characteristics include the water distribution method, media characteristics, media bed depth, gas/liquid loading rates, inlet DO concentration and operating pressure. Their main disadvantage is fouling due to the accumulation of organics and particulates on the media over time.

Packed columns have two additional advantages:

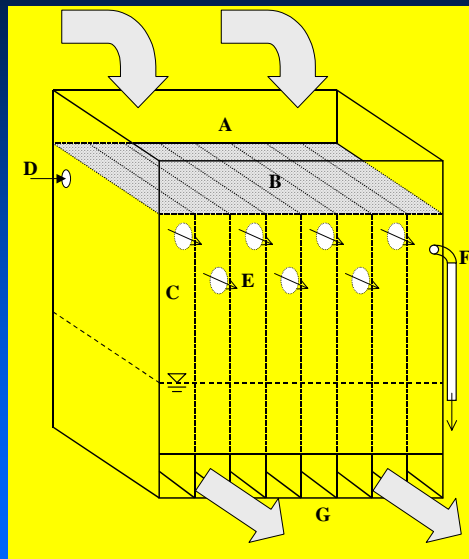
- Provide nitrification
- Provide CO₂ gas stripping

The above features allow to some degree that a packed tower can serve as the complete water conditioning system for lowly loaded systems.

Hydraulic loading rates should be at least 10 gpm/ft² (7 kg/m²s), and can be as high as 70 gpm/ft² (48 kg/m²s). Excessive hydraulic loadings will cause the packing to be flooded and must be avoided.

Gas Transfer Options

LHO's



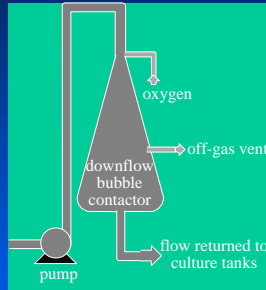
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LHO's

Low Head Oxygenators (LHO) are being used more frequently, particularly because of their adaptability to high flows using minimal hydraulic head, hence their name Low Head Oxygenator. The original LHO design was developed and patented by Watten (1989). LHO's vary in configuration, but all are fundamentally similar in operation. These units consist of a distribution plate positioned over multiple (5 to 10) rectangular chambers. Water flows over the dam boards at the end of a raceway or is pumped upwards from an indoor fish tank, through the distribution plate, and then falls through the rectangular chambers. These chambers provide the gas-liquid interface needed for mixing and gas transfer. The streams of falling water impact a collection pool at the bottom of each chamber where the effluent water flows away from each chamber equally in parallel. All of the pure oxygen is introduced into the outer or first rectangular chamber. The mixture of gases in the first chamber, which now has a diluted oxygen concentration passes, sequentially through the remaining chambers. The gaseous mixture will decrease in oxygen concentration from chamber to chamber as the oxygen is continued to be absorbed. Finally the gaseous mixture will exit from the last chamber. This gas is referred to as off-gas. Each of the rectangular chambers is gas tight and the orifices between the chambers are properly sized and located to reduce back-mixing between chambers.

Gas Transfer Options

Aeration Cone Or Down-Flow Bubble Contactors



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Aeration Cone Or Down-Flow Bubble Contactors

The aeration cone, bicone, or downflow bubble-contact aerator consists of a cone-shaped cylinder or a series of pipes with reducing diameters. Water and oxygen enter at the top of the cone, flow downward, and out. As the cone's diameter increases, the water velocity decreases, until the downward velocity of the water equals the upward buoyant velocity of the bubbles. Thus, the bubbles are held in suspension, until they dissolve into the water. The performance of aeration cones is determined by gas and water flow rates, influent DO concentration, cone geometry and operating pressure. Absorption efficiency range from 95–100% with effluent concentrations from 30 to 90 mg/L. Commercial units are available that transfer from 0.4 to 10.8 lbs of oxygen per hour (0.2 to 4.9 kg/hr) at 25 mg/L, at flow rates from 45 to 600 gpm (170 to 2,300 Lpm).

Gas Transfer Options

- *Diffused Aeration (Air Stones)*

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Diffused Aeration (Air Stones)

Due to their low absorption efficiency, the use of diffusers or air stones have been limited mainly to emergency oxygenation and fish live-haul systems. Although some of the recent fine-bubble diffusers (bubbles 100 to 500 microns) do perform well in deep tanks (50% oxygen transfer efficiency), they require a high pressure source of oxygen (25–50 psi) and are subject to both chemical and organic fouling.

Gas Transfer Options

Oxygen Injection



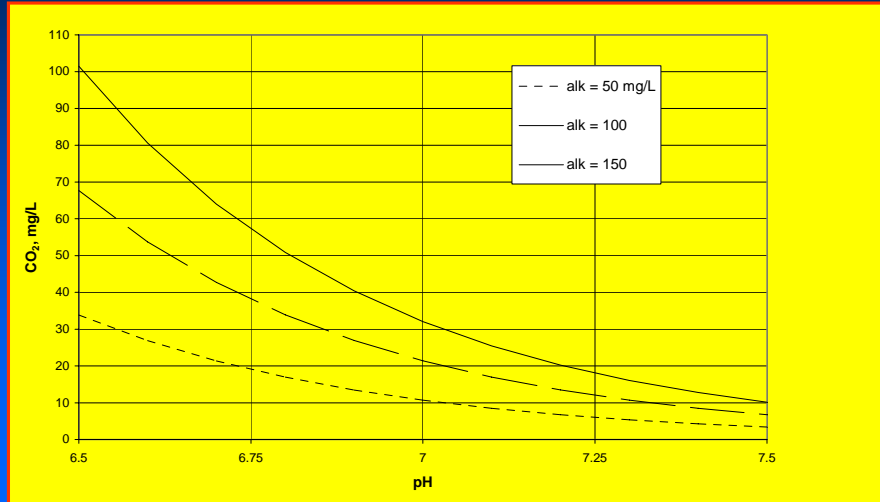
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Oxygen Injection

The most widely used form of oxygen injection takes advantage of the increased pressure available when pumping water. Oxygen is injected through a venturi nozzle or orifice, creating a fine bubble suspension in the pressurized line. Pressures of 30–235 psi (2 to 22 atmospheres) are needed to achieve satisfactory absorption, with contact times of 6–12 seconds. Absorption efficiency ranges from 15 to 70% with effluent DO concentration from 30–50 mg/L.

Gas Transfer CO₂

Degassing: Carbon Dioxide (Nitrogen)



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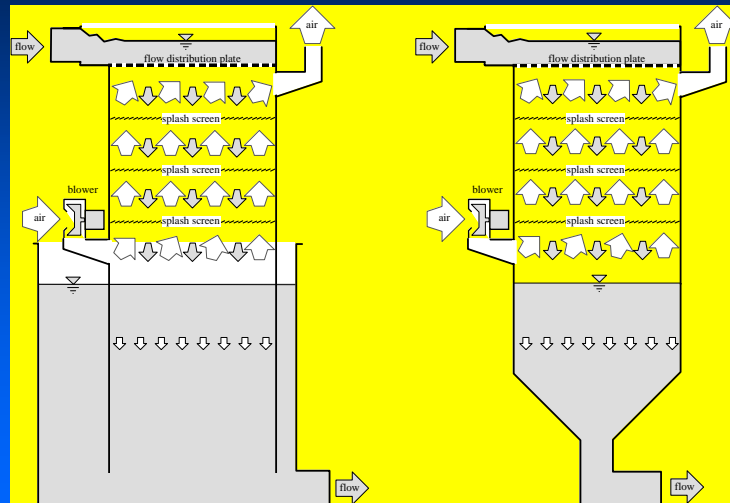
Carbon dioxide is introduced into the water through respiration of the fish and bacteria. As stocking densities increase and water exchange rates decrease, dissolved carbon dioxide will become a limiting factor to production. When stocking densities were less than 30 to 60 kg/m³, conventional aeration systems would generally provide sufficient removal of CO₂ in the process of transferring oxygen into the water with airstones and surface agitation or water falls. However, as carrying capacities have increased to 100 kg/m³ and higher in order to be economically competitive, proactive control of CO₂ removal must be included in any successful fish production system.

For every mole of oxygen that is consumed, one mole of carbon dioxide is produced. Alternatively, on a mass basis, for one gram of oxygen consumed; 1.38 g of carbon dioxide is produced. Calculating the concentration of dissolved carbon dioxide is complicated in that CO₂ is part of a chemical equilibrium system that includes carbon dioxide (CO₂), carbonic acid (H₂CO₃), bicarbonate (HCO₃⁻) and carbonate (CO₃⁻) ions. As a result, the concentration of any one ion is pH dependent, and to accurately determine their concentrations, values for pH, alkalinity, and temperature must be known. The Figure above shows the effect of pH on the concentration of CO₂ as a function of pH for alkalinities of 50, 100 and 150 mg/L. Note that CO₂ concentration is proportional to alkalinity.

Carbon dioxide is toxic to fish because it reduces the capacity of the blood to transport oxygen. As the CO₂ concentration in the water increases, so does the blood CO₂ level. The presence of CO₂ in the blood reduces the ability of hemoglobin to bind oxygen molecules, a condition often referred to as the Bohr or Root effect. The safe operating levels of CO₂ depend on the species, development stage, and overall water quality. For tilapia and striped bass, concentrations of CO₂ as high as 60 mg/L have shown no adverse affect. For trout, values of 9–30 mg/L are generally assumed safe. Carbon dioxide may also affect the fish and the biological filter's bacteria by reducing the overall system's pH.

Gas Transfer CO₂

Carbon Dioxide Stripping: counter-current air-stripping columns



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Removal of dissolved carbon dioxide is easily done through a gas exchange process, but accurately predicting the removal rate is very difficult. Unlike dissolved oxygen, carbon dioxide is part of a complex equilibrium system, where as CO₂ is removed, a shift in the carbonate carbon equilibrium occurs (see Chapter 2 for much more detail). For example, bicarbonate (HCO₃⁻) acts as a reservoir of carbon dioxide, replenishing dissolved CO₂ as it is removed from solution. In addition, since the concentration of CO₂ in intensive systems is typically more than 20 to 100 times the ambient saturation concentration, the off gassing of CO₂ has a significant effect on the contacting gas. What this means in practice is that air bubbling through or passing over a gas exchange system is quickly saturated with CO₂.

Thus, large volumes of air per unit volume of water are required to strip off CO₂. For example, in normal aeration, gas to liquid ratios (G/L) are usually less than 3 to 1 (3 unit volumes of gas to every unit volume of water). In oxygenation, the G/L ratio is between 0.05:1 to 0.3:1. But for CO₂ stripping, the G/L ratio is between 5:1 to 10:1. Using a packed column and gravity flow of water to supply the packed column is one of the easiest ways to strip water of CO₂.

Gas Transfer CO₂

Carbon Dioxide Stripping: counter-current air-stripping columns

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The open packed column for carbon dioxide removal is a vertical tower filled with plastic packing similar to a pure oxygen packed column absorber. In operation influent water is introduced at the top of the column and is distributed uniformly over the plastic packing with a perforated plate, spray nozzle, or spray bar. Water flows downward through the packing and is broken up creating a large gas-liquid interfacial area for gas transfer. To overcome the potential for clogging or biofouling of plastic packing alternative water breakup approaches have also been utilized. It is common for the stripping column to have no packing or just a few splash screens to break the water up as it travels through the column. If plastic packing is used provisions are made to allow for particulates to pass through the media by using high porosity packing or packing that has an unobstructed downward path through the column.

Taking advantage of the water breakup created by the packing media and passing large volumes of air through the column achieve carbon dioxide removal. Fresh air has a low gas phase concentration of carbon dioxide (350 ppm) and is suitable for providing an adequate driving force for carbon dioxide gas transfer. Carbon dioxide is degassed from the water being treated and is carried out of the column with the fresh air blown through. In contrast with pure oxygen devices that use volumetric gas flow to water flow (G/L ratio) ratios of 0.3–5%, carbon dioxide stripping columns use G/L ratios of 500–2,000%. Low horsepower, high volume, ventilation-type air blowers provide the large amounts of airflow required for efficient carbon dioxide removal.

Stripping column design heights are generally limited to 1.0 to 1.5 m (3.3–4.9 ft) because of the diminishing returns on removal performance that correspond to packing heights greater than 1.5–2.0 m (4.9–6.6 ft). Hydraulic loading for carbon dioxide stripping columns are reported to range between 0.61–2.51 Lpm/m² (25–102 gpm/ft²). However, values towards the lower end are recommended to reduce the back-pressure on the blowers when the column design calls for packing depths exceeding 1 m (3.3 ft).

Gas Transfer HLR

Gas Transfer Device	Gas Species	Hydraulic Loading Rate	
		kg/m ² s	gpm/ft ²
Packed Columns			
Sealed columns	oxygen	<166	<244
High Pressure Columns	oxygen	45–246	66–361
Pure Oxygen, atmosphere pressure	oxygen	73	107
Open to atmosphere	carbon dioxide	17–34	25–50
Spray Tower			
	oxygen	35–95	51–140
Low Head Oxygenator (LHO)			
	oxygen	34–68	50–100
Down Flow Bubble Contactors (Speece cone)			
at inlet	oxygen	1,800	2650
at outlet (to keep bubbles in)		150	220
U-Tubes			
	oxygen	2,000–3,000	2,940–4,410

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Summary of Hydraulic Loading Rates

The many devices just discussed for gas transfer all have associated hydraulic loading rates that are considered appropriate for the particular device. The Table above summarizes these for ease of reference. These values should be seen as guidelines and particular applications may warrant substantial deviation from the listed values. Exercise caution when doing so, though.

Gas Transfer

Installation and Safety Concerns



Recirculating Aquaculture Systems Short Course

Installation and Safety Concerns

The handling and use of pure oxygen can be hazardous. Almost all substances will burn and in some cases explosively in an oxygen enriched environment. There have been rumors of used air stones exploding, when transferred to pure oxygen systems, when the organic residue oxidized. Special care and materials should be used in the construction and installation of pure oxygen systems. Stainless steel or copper tubing is recommended for oxygen lines, and both piping and fittings should be cleaned of grease and oil, which can present a fire hazard. Petroleum products should never be used on hardware that handles or contacts pure oxygen. Fittings and valves that have been specially cleaned and packaged for pure oxygen applications are available. Liquid oxygen is very, very cold and installation and servicing of storage containers should be left to the professionals.