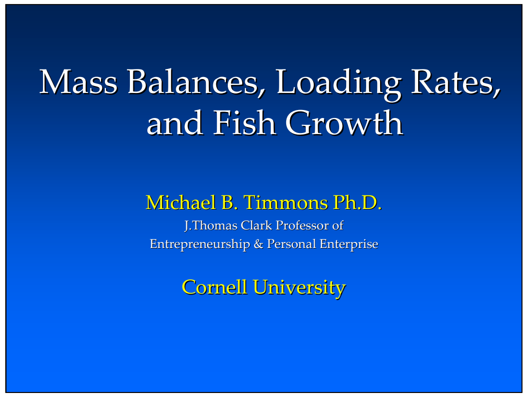
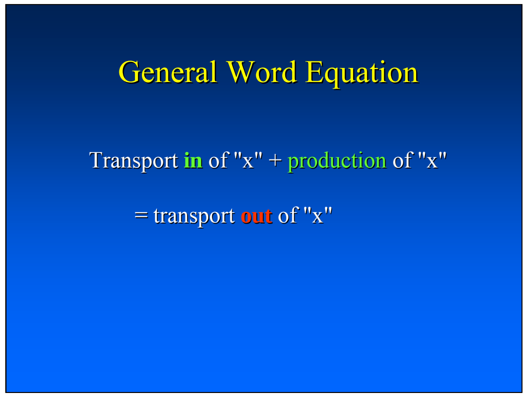


In our opinion, this presentation is the most fundamental of all the short course. This is where you calculate the required flows to maintain some desired level of a particular water quality parameter, e.g. oxygen, ammonia, NH_3, CO_2 or TSS. You must be able to do these calculations in order to calculate the required flow rates and sizing of the individual unit processes that make up an intensive recirculating system design. Later in the book (or the course) we will give you software to do the calculations, but you need to understand the fundamentals behind the spreadsheet calculations

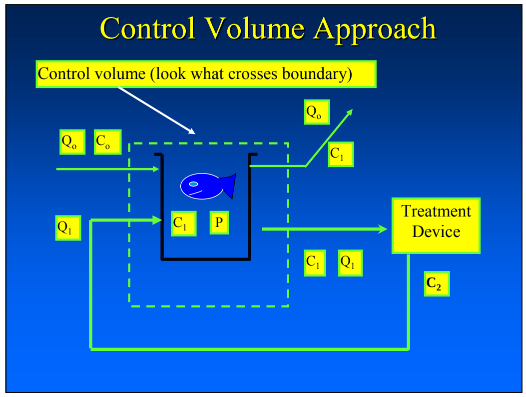
Water flow is the mechanism by which oxygen is transported into a fish culture vessel and the waste products being generated within are removed. The design of a recirculating aquaculture system (RAS) should insure that the important parameters affecting water quality and fish productivity, e.g., oxygen, ammonia, carbon dioxide, and suspended solids are properly balanced. This requires calculating the value of each of these parameters independently to determine the thresholds for each. Then, having done the necessary calculations, the system must be operated at the highest flow rate possible while still maintaining a particular parameter at or below its maximum tolerable or design value, e.g., ammonia. Obviously, the maximum flow rate possible while maintaining one particular parameter may be too high for maintaining another. The same mass balance approach can be utilized on any variable affecting water quality. It simply comes down to balancing the transport in, the production of a particular parameter within the culture tank, and the transport out.



In word equation form, we like to say:

*Transport **in** of "x" + **production** of "x"   =   transport **out** of "x"*

The production term can be the production of oxygen, ammonia, suspended solids, or CO2. Note that the production term can be <u>negative</u>, meaning consumption of a certain component, e.g., oxygen. Keep repeating this word equation until it makes sense to you! Note we are NOT talking about concentrations here. We are talking about a mass quantity of some “stuff”, referred to as “x” in the word equation.



This is the control volume approach. Engineers like to depict mass transport across some "imaginary" box that designates the vessel or container that we are trying to analyze. We can depict a mass balance for the general case where part of the flow is recirculated and part of the flow is flow-through as:

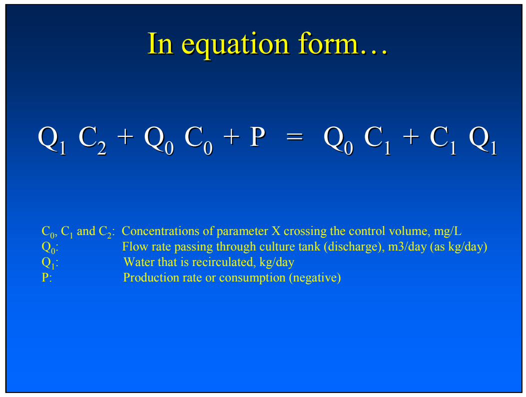
We are assuming a completely well mixed tank and that the tank has reached a non-changing condition with respect to time or steady-state conditions. The box outside the fish tank represents some treatment device or process that changes the concentration of the noted parameter "x". (Note: there could be several treatment devices, each treating a different water quality variable.)

C_0, C_1 and C_2: Concentrations of parameter X crossing the control volume, mg/L

Q_0: Flow rate passing through culture tank (discharge), m^3/day (as kg/day)

Q_1: Water that is recirculated, kg/day

P; Production rate or consumption (negative)



To obtain accurate and reliable results from these equations, it is essential that each of the terms or products of terms in the above equation are represented by the same unit value, e.g.,

$$kg_{oxygen} / day$$

For example, the unit balance example for a transport of oxygen flowing into the tank would be:

$$QC = kg_{water} / day \ * kg_{oxygen} / kg_{water} = kg_{oxygen} / day$$

Unit Balance

(flow, Q) x (concentration, C)

$$Q \cdot C = \frac{kg_{water}}{day} \cdot \frac{kg_{oxygen}}{1{,}000{,}000\,kg_{water}} = \frac{kg_{oxygen}}{day}$$

We like to express my water quality concentrations as kg of “x” per 1,000,000 kg of water. This is the same as PPM or mg/L, but it makes the math more straight forward. We also like to work in terms of these quantities on a DAILY basis, since you feed fish on a daily basis.

If we were doing a mass balance for oxygen, then all terms or products would need to have the same units of kg oxygen per unit time. It is convenient to use "day" as the time unit, since growth rates and feeding rates are generally measured on a per-day basis.

BE CAREFUL to be consistent with unit designations.

Transport is the key term in these calculations, and it is defined as the product of flow and concentration. For example, the remainder of oxygen transport into the tank minus the allowable minimum level of oxygen departing the tank defines the oxygen available for fish growth. Flow is measured as volume per time or mass per time, and will be usually defined in terms of:

gallons per minute, gpm

liters per minute, Lpm

kg per sec, kg/s

m^3/s

Typically, most water quality parameters are expressed in terms of:

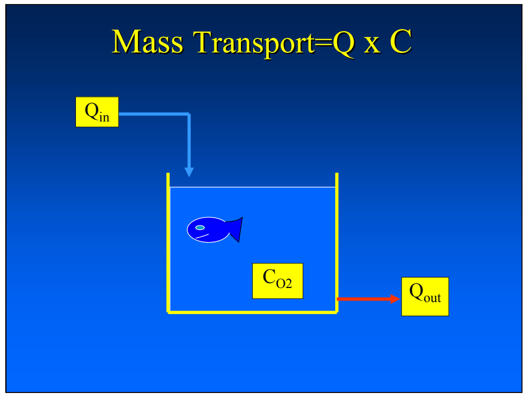
mg / liter or mg/L

The usage of mg/L is often called or referred to as:

ppm or parts per million.

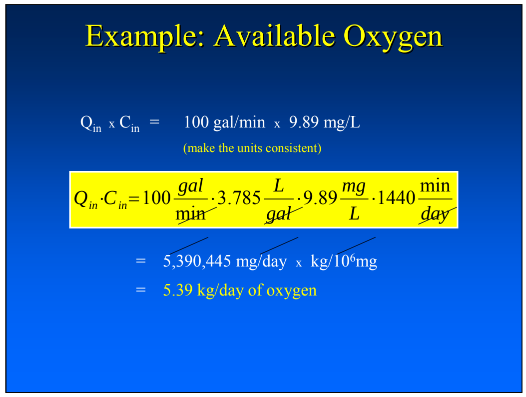
These values are the same.

Thus: 10 mg/L oxygen is the same as 10 ppm oxygen



Just to emphasize it one more time, mass transport is FLOW times CONCENTRATION

Now, to reinforce your understanding, let's calculate the available oxygen to support fish growth assuming a mass flow of water of 100 gpm of saturated inlet water at 60°F at an elevation 800 feet above sea level. Using the charts from the appendix, the dissolved oxygen concentration at 60°F (15 °C) at an elevation 800 feet above sea level can be estimated to be 9.89 mg/L.



To repeat, this is a calculation to see the available oxygen entering a control volume (CV) or fish tank if the entering water has an oxygen concentration of 9.89 mg/L and the flow into the CV is 100 gpm.

For the mentioned flow rate of 100 gpm of water and with the incoming water having a concentration of 9.89 mg/L, the mass of oxygen transported into the tank on a daily basis is ("gpm" units are used since they are common terminology in US):

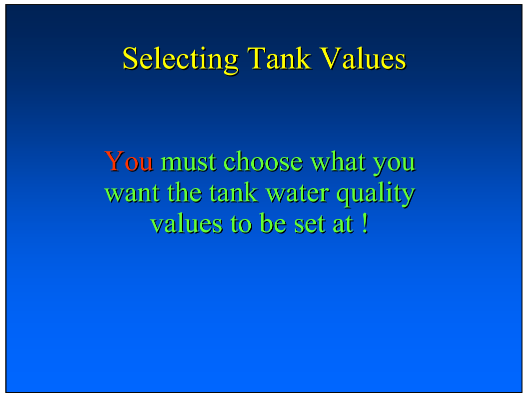
$$Q_{in} * C_{\text{in oxygen}} = 100 \text{ gal/min} * 9.89 \text{ mg/L}$$

Now, make the units consistent:

$$= 100 \text{ gal/min} * 3.785 \text{ L/gal} * 9.89 \text{ mg/L} * 1440 \text{ min/day} * \text{kg}/10^6 \text{ mg}$$

$$= 5.39 \text{ kg } O_2 / \text{day}$$

This then is the oxygen available to the culture vessel on a daily basis to support fish growth and bacteria action. However, the water leaving the tank must still be at the minimum level necessary to support fish growth, e.g., 5 mg/L, so only a portion of the total available oxygen can be used.



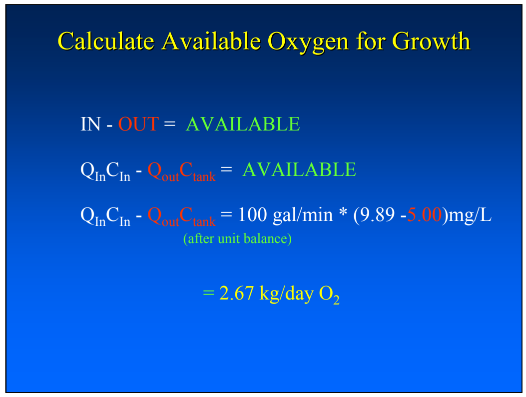
For some reason, a lot of folks have trouble with this part. You must select design or target values for the water quality concentrations you will attempt to meet or "better". For example, in the current example, let's choose a design value of 5.0 mg/L for the oxygen levels in the tank. This means when the water LEAVES the tank, it is supposed to be at or above 5.0 mg/L.

Water Quality Design Guide

Parameter	Tilapia	Trout
Temperature, °F	75 to 85	50 to 65
Oxygen, mg/L	4 to 6	6 to 8
Oxygen, mm Hg	90	90
CO_2, mg/L	40 to 50	20 to 30
TSS, mg/L	<80	<10
TAN, mg/L	<3	<1
NH_3-N, mg/L <0.6	<0.02	
Nitrite-N. mg/L	<1	<0.1
Chloride, mg/L	>200	>200

A difficult concept to grasp for most is that in performing the mass balances, the designer/manager must choose design or target operating conditions. These are the "C" values in the mass balance equation shown in the culture tank. These design numbers are species dependent and are continually being refined for RAS applications. Our recommendations are given above for a common warm (tilapia) and cool (trout) water species.

Calculating the minimum flows required to maintain targeted values for water quality (and then using the largest minimum value found for all the different water quality variables) will show how sensitive the calculated flow rates are to the value selected for the design value. A typical scenario is to select a value, do the calculations, realize that there is no way you could afford to supply such a high flow rate, and then start to make adjustments in the targeted values, e.g., 4 mg/L oxygen is probably OK instead of the 6 mg/L you originally chose, etc, etc. In the end, one must choose realistic values and then stay with these choices and the ramifications of the resulting flows required to maintain the mass balances. Do **NOT** ever compromise on the required flow rates. **You will be sorry if you do**.



The corresponding oxygen per day transported out if the tank concentration is 5 mg/L is 2.72 kg/day. The difference between incoming and outgoing is what is available for supporting fish growth and biological activity.

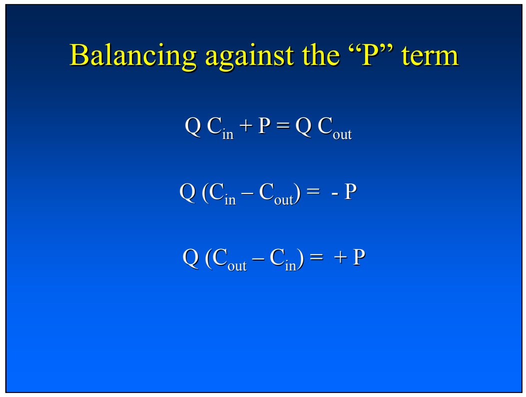
The available oxygen is then (same as previous example except now a Cout for the discharge water is defined):

$$Q\,(C_{in} - C_{tank}) = 100 \text{ gal/min} \;*\; (9.89 - 5.00) \text{ mg/L}$$

Now, make the units consistent:

$$= 100 \text{ gal/min} \;*\; 3.785 \text{ L/gal} \;*\; (9.89 - 5.00) \text{ mg/L} \;*\; 1440 \text{ min/day} * \text{kg}/10^6 \text{ mg}$$

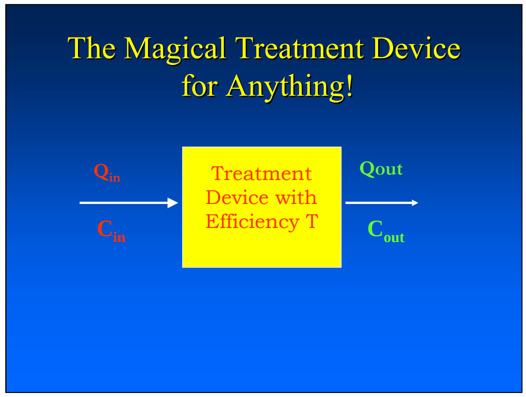
$$= 2.67 \text{ kg } O_2 \text{ / day}$$



Returning to the general mass balance, the simplest RAS case is where all water flow is recirculated and there is no discharge. In this situation, the Q_0 terms drop out, since $Q_{in} = Q_{out}$.

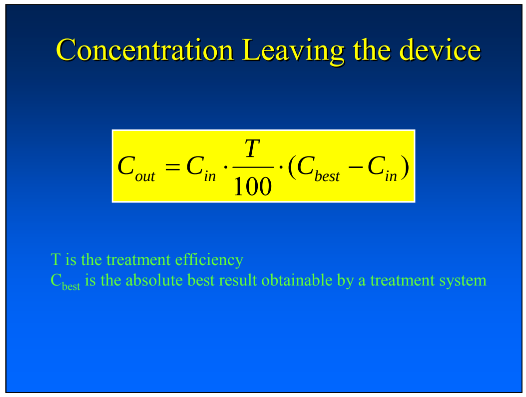
It is REALLY easy to get your signs mixed up here. The production term can be positive (ammonia production) or negative (oxygen is consumed) AND remember a negative x negative = a positive number.

The above equation is only valid on a totally closed system, I.e. there is no freshwater makeup, which is basically true for RAS type operations. If you do have significant water exchange of say more than 50% tank volumes per day, then do the more general mass balance to calculate flows (Q)



We must treat the water in the fish tank by sending it to some type of treatment device. We describe the treatment efficiency as “T, % “. We can calculate the concentration of the particular water quality parameter leaving the treatment device by knowing what the “absolute” best the treatment device could achieve.

Solving the general mass balance equation with the "magical" treatment box, we need to determine the concentration of each particular water quality parameter leaving the treatment device, so that the mass flow of the water quality parameter into the fish culture tank can be determined and the mass balance solved (C_2). Looking now at only the treatment device depicted above, the treatment box could be a biofilter, a CO_2 stripper, or a solids settling chamber. Each will have its own treatment efficiency for the particular water quality parameter it is designed to treat. We just use the box as a symbolic depiction of this treatment device.

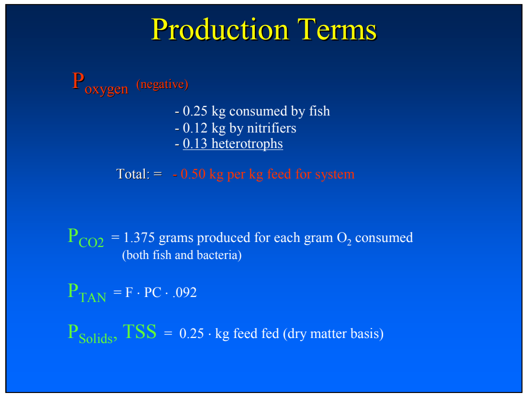


Looking at this treatment box and doing a mass balance on the control volume, you can solve for the leaving water quality concentration Cout. Since the water flow in equals the water flow out, the C_{out} term can be solved for directly:

$$C_{out} = C_{in} + T/100 \times (C_{best} - C_{in})$$

where, T is the treatment efficiency and C_{best} is the absolute best result obtainable by a treatment system, e.g., zero ammonia or saturated oxygen, zero suspended solids.

We have adapted the term "C_{best}" to represent what the treatment device is trying to do. If you had the perfect treatment device, the device is still limited by basic physical laws as to what it can achieve. Thus, the reference to *best*. Note that if the device is an oxygen addition unit, the C_{best} term can be increased above atmospheric concentration values for oxygen by increasing the partial pressure above atmospheric oxygen partial pressure in the device. For example, a pure oxygen device will have a C_{best} value of roughly five times the C_{best} value that is available if normal air used at atmospheric pressure, e.g., trickling tower. C_{best} for most other parameters should be fairly obvious to the reader, e.g., ammonia and TSS are zero, but CO_2 will be around 0.5 mg/L since there is some CO_2 in the air.



The "P" term in the mass balance equation represents the production of some pollutant or consumption term. These terms in an RAS system can all be proportionately related to the fish feeding rate. In principle, if you are not feeding the system, there is no pollution. This generalization is valid, because even ammonia production rates reduce 10 fold within a day or so, once feeding activity has ceased. Oxygen consumption is also reduced by approximately 50% and fecal production goes to zero. However, the idea in any production system is to grow the animals, and to grow, they must be fed, so we relate the production terms exclusively to feeding rates as follows:

P_{Oxygen} = - 0.25 kg per kg feed consumed by fish (a negative production term)
- 0.12 kg per kg feed consumed by nitrifying bacteria
- 0.13 heterotrophic bacteria (estimate, can be as high as 0.5)

= - 0.50 kg (sum of above) per kg feed for system including nitrifying and heterotrophic bacteria

These terms are negative since they "consume" oxygen from the system as opposed to adding a mass quantity to the water column.

The heterotrophic bacteria load can be as much as 0.5 kg of oxygen per kg of feed fed if the system has poor solids removal.

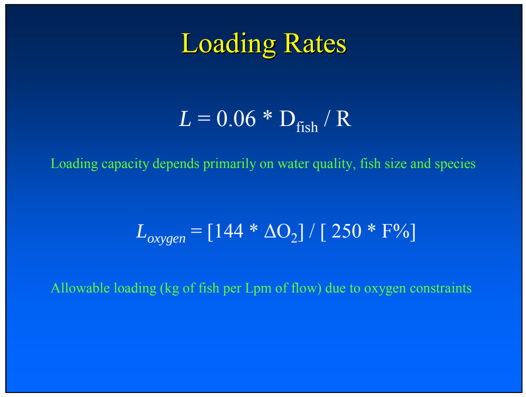
P_{CO2}= 1.375 grams produced for each gram O_2 consumed (both fish and bacteria)

$P_{TAN} = F \cdot PC \cdot .092$

P_{Solids}, TSS = 0.25 · kg feed fed (dry matter basis)

(literature gives values from 20% to 40% of feed fed on dry basis)

Note that the oxygen consumption term can be much higher when solids management in the RAS is not good; a safe number for design purposes might be closer to 1 kg of oxygen per 1 kg of feed used (this would be twice as high as the above suggestion)



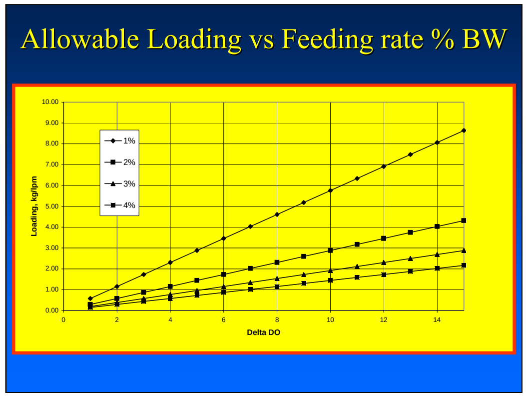
The relationships of production capacity to flow exchanges and space are important to aquacultural engineers. The terminology "loading" (L) is used to describe the fish mass that can be maintained per unit of flowing water, kg fish per liter per minute flow (kg/Lpm). Fish density (D_{fish}), defined as kg fish per cubic meter of space (kg/m^3), combined with the number of water exchanges per hour (R) through the rearing unit produces the loading rate (L):

$$L = 0.06 * D_{fish} / R$$

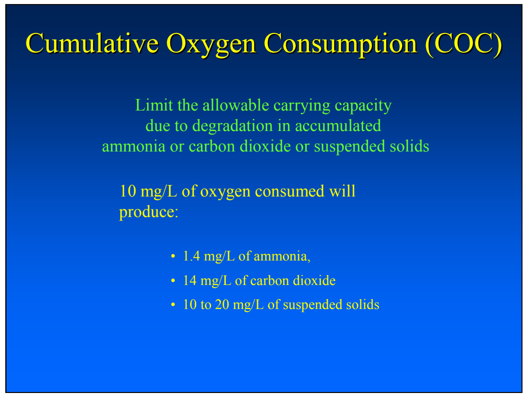
The constant 0.06 in the above equation converts Lpm to m^3/hr (1.0 Lpm · 60 min/h = 60 L/h or 0.06 m^3/h, there are 1,000 L in a m^3). The loading capacity depends primarily on water quality, fish size and species. Using this equation and assuming that fish metabolism requires 250 grams of oxygen for each kg of feed fed (no allowance for nitrification), the allowable loading (kg of fish per Lpm of flow) due to oxygen constraints is:

$$L_{oxygen} = [144 * \Delta O_2] / [\ 250 * F_{\%}]$$

The ΔO_2 term in this equation represents the allowable drop in oxygen from inlet to outlet. For example, if the inlet DO is 11.0 mg/L and the outlet is designed to maintain oxygen above 5 mg/L, then the ΔO_2 is 6.0 mg/L. This equation is graphically demonstrated in the next slide for various feeding rates and allowable changes in oxygen concentration.



Allowable fish loading in the culture vessel based upon the change in dissolved oxygen from inlet to outlet (Delta DO) and the percent body weight per day for the fish feeding rate (to convert to lbs per gpm, multiply by 8.33). This chart can serve as a quick "look-up" for the loads you can impose on a fish tank vessel.



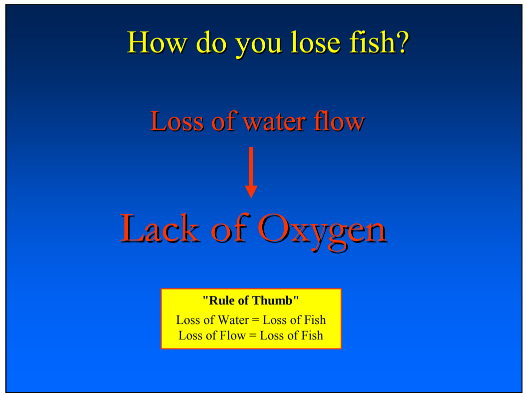
As fish densities increase, minimum oxygen levels are better maintained by using pure oxygen systems, which permit inlet oxygen concentrations to be maintained at multiples of dissolved atmospheric concentration levels (see Chapter 8). However, other water quality parameters will begin to limit the allowable carrying capacity due to degradation in accumulated ammonia or carbon dioxide or suspended solids. The term for this condition is the cumulative oxygen consumption (COC) level. From basic stoichiometry and the production values for ammonia, solids, and carbon dioxide associated with feeding, then:

•10 mg/L of oxygen consumed will produce up to 1.4 mg/L of ammonia,

•14 mg/L of carbon dioxide, and

•10 to 20 mg/L of suspended solids.

Maximum allowable or safe densities (D_{fish}) are much more difficult to ascertain than are maximum loadings. It still seems to be a very subjective process and has much controversy. Density is primarily a function of fish size, species, and the characteristics of the rearing environment and management skill. New growers tend to overestimate their own safe loading densities and assume they can establish and sustain densities from the very beginning that in fact require expert management skills. **Do NOT fall into this trap.** You will kill fish. New growers should target about 1/2 the densities recommended in this book for expert growers.



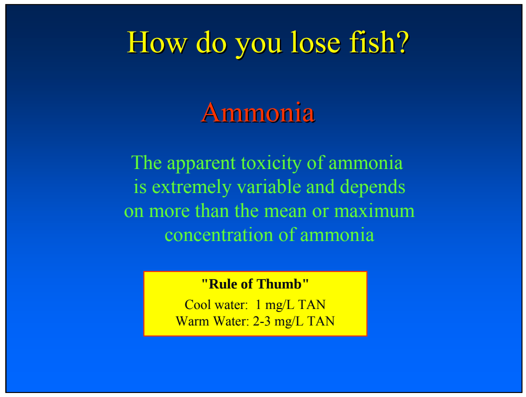
The major reason most fish die is from lack of oxygen due to a loss of water flow. This is because oxygen is consumed at a fairly high rate (fish metabolism) and oxygen is transported by water flow. Due to low inherent concentrations of oxygen, "high" flows are required to transport the required oxygen. Flows required to maintain a satisfactory oxygen level are generally the controlling flow rate parameter when solving the series of mass balance equations to determine the most restrictive parameter. Even a partial loss of flow will generally result in insufficient oxygen for the fish, resulting in death.

Effective methods of monitoring and control are discussed in Chapter 9 in detail, but remember the above rule; always sense and monitor these two activities in at least two independent ways. If you don't, we guarantee that you will lose fish and eventually you will lose fish catastrophically.

Oxygen concentrations versus temperature and salinity are provided in the Appendix. For salmonids, as a group, the rearing unit effluent should contain from 6.0 to 8.0 mg/L dissolved oxygen (DO). For catfish and tilapia, allowable minimum levels are much lower than for salmonids, e.g., 2 or 3 mg/L, while it is certainly recommended to stay much closer to 5 or 6 mg/L.

Beyond the general rule that each unit of feed will require 0.25 units of oxygen for fish metabolism, usage rates will depend mostly upon the type of fish being considered. Westers (1979) uses 200 to 250 g per kg of feed fed, while Pecor (1978) recommends using 110 g per kg of feed fed for esocids, such as the tiger muskellunge, a coolwater, non-active fish. Huisman (1975) uses 230 g for the common carp, as a warmwater representative. These values are consistent with our general recommendation of 250g O2 per kg of feed fed for fish oxygen needs.

Finally, remember that not only do the fish require oxygen, but also the biological filter is just as critically dependent upon adequate oxygen levels to support bacteria metabolism. The DO concentration within the filter must be maintained at or above 2.0 mg/L to insure that the rate of nitrification in the filter does not become limited because of oxygen depletion (Kumar, 1984; Manthe et al. 1988). Always measure the DO coming off the biofilters and if the concentration starts to approach 2.0, then take corrective action, e.g., increase flow rate through the biofilter by increasing the hydraulic loading rate on the filter.

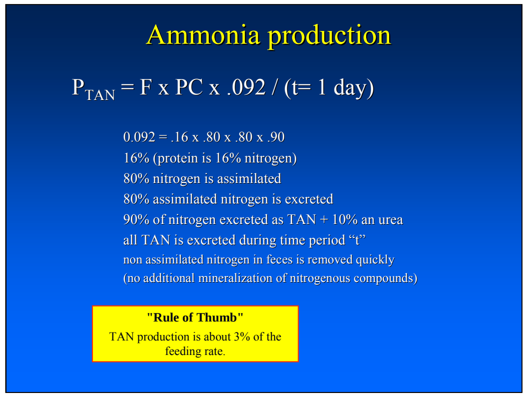


There is considerable confusion about ammonia. Definitive values for the toxic levels of ammonia and the differentiation between the toxic NH_3 form and the supposed non-toxic NH_4^+ have never been determined. Meade (1985) reviewed the published literature on the effects of ammonia on fish and concluded:

A truly safe, maximum acceptable concentration of un-ionized, or of total ammonia, for fish culture systems is not known.

The apparent toxicity of ammonia is extremely variable and depends on more than the mean or maximum concentration of ammonia.

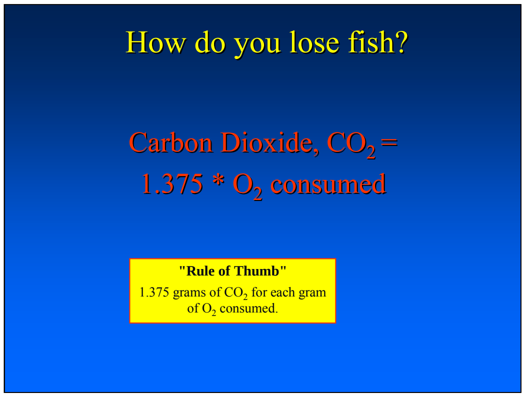
The European Inland Fishery Advisory Commission (EIFAC) of FAO has set 0.025 mg/L as the maximum allowable un-ionized ammonia (NH3 or ANH3-N). Note, this means that tank ammonia levels (TAN) can exceed 10 mg/L if pH is maintained below 7.0. We would be very uncomfortable using such a high design value. What if the pH rose to 7.3 and doubled your NH3? As seen in the table of design values for water quality, we use rule of thumb values of 1 mg/L TAN for cool water and 2 or 3 for warm water fish. You should always check your TAN target value selection by assuming some pH that you intend to maintain and see if your NH3 concentrations will exceed the 0.025 mg/L value using the ammonia-ammonium pH Temperature tables from the Appendix. If so, rethink your design carefully before proceeding.



The individual assumptions about digestion and ultimate production of ammonia that is diffused across the gill and excreted directly via the feces all lack crispness in their assignment. Thus, we tend to see the rate of ammonia generation as being a "soft" number. For simplicity, one could simply assume 10% of the protein in the feed becomes the ammonia-N generation rate.

The above equation represents a conservatively high estimate of the P_{TAN} production rate. We use the time period as one day, while others will use the time period between feedings. In RAS, feed can be fed uniformly over a 24 hour period, thus distributing the ammonia load uniformly over the entire day as well. If a uniform 24 hour feeding is not used, then the equation should be adjusted and the time period should be the time between feedings or if a single feeding per day is used, then use 4 hours as the time period as an estimate of the time for the ammonia to be excreted from a feeding event. The assumption that all of the TAN is excreted in a finite period of time (t) between feedings is founded in evidence that metabolic activity increases during the hours following feedings (Page and Andrews, 1974; Ruane et al. 1977). Although the value of t is dependent on many biological variables, experience has indicated that fish metabolic activity peaks from 1 to 4 hours following feeding. One quickly will conclude that many smaller feedings evenly spaced during the day would serve to minimize high values of P_{TAN}. In fact, this is a strategy employed in the production of fish in tanks through the use of automatic feeders or demand type feeders.

Note that in the above "exact" equation, there are a lot of "soft" terms, e.g. 80% of the Nitrogen in the feed is assimilated. This assumes the diet is properly designed for the current status of the fish, good feed ingredients are used, and the fish are fed properly with good management. There are just a "few" ifs in there ! Note that as a rule of thumb, if you take 10% of the protein content of the feed and feeds are generally between 30 to 40% Protein, the TAN production rate is about 3% of the feeding rate.



Carbon dioxide is an important, but largely overlooked water quality limiting parameter. This is probably because until recently, most systems were generally low density (less than 40 kg/m^3) and relied on aeration as the main means of supplying oxygen. This type of management also kept CO_2 values at low levels, e.g., less than 20 mg/L. However, loading rates have increased in recent years, and it became necessary to inject pure oxygen into these systems, instead of using aeration. As result, the natural stripping of CO_2 that occurs when using aeration systems was no longer taking place. We now need to apply other means for CO_2 control.

The generation of CO_2 is based upon chemical stoichiometry by relating CO_2 production to oxygen consumption (1.375 is the ratio of molecular weights of the two gases, 44/32):

CO_2 = 1.375 grams produced for each gram O_2 consumed (both fish and bacteria)

A key point in the above discussion is that fish successfully acclimate to slowly changing water quality conditions, such as increases in the level of CO_2, but are adversely affected by sudden changes of water condition. Using CO_2 as an example, fish acclimated to CO_2 levels of 20 mg/L may die if exposed to a sudden spike to 80 mg/L CO_2 while other fish may exhibit good growth and feed conversion ratios at a gradually created but sustained level of 80 mg/L CO_2. An advantage of RAS is that system water quality can be maintained at fairly uniform values in a normally functioning system, but failures or malfunctions of the system that cause certain water quality parameters to fluctuate widely may cause fish to suffer or die.

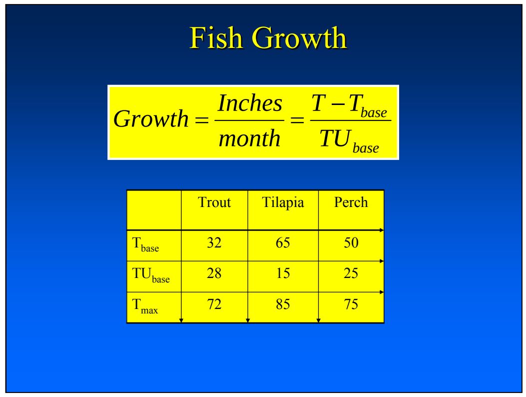
The effective control of solids generated in RAS is probably the most important task that must be accomplished to ensure long-term successful operation of an RAS. This aspect of RAS is discussed in more detail in Chapter 6, but is also presented here as the suspended solids are a component of water quality. The quantity of suspended solids or Total Suspended Solids, TSS, generated per unit of feed being fed is estimated as:

$$TSS = 0.25 \cdot \text{kg feed fed (dry matter basis)}$$

(from 20% to 40% of feed fed dry basis)

TSS is treated as a dilute waste. TSS design concentrations in RAS will be in the 10 to 80 mg/Liter range. Even after concentrating TSS with some type of treatment process, a certain volume of water will still contain only around 0.5 to 1% solids on a dry matter basis. In comparison, cow manure is 20% solids. TSS captured in a settling basin has a fluffy consistency and will require substantial volumetric space depending upon frequency of cleaning. As a "rule of thumb", assume that each kg of dry feed fed will produce approximately 8 liters of liquid waste, i.e., one lb feed produces one gallon of manure.

Nitrate nitrogen (NO_3) is the end product of the nitrification process. In general, concentrations of nitrate are not extremely adverse to RAS water quality. We have maintained some salmonid systems at nitrate levels above 1,500 mg/L without impact on the fish. Nitrogen should be conserved throughout the nitrification process. Thus, if 1 kg per day of TAN is being produced, then 1 kg of nitrate-N is being produced. The equilibrium concentration of nitrate will therefore be directly dependent upon the overall water exchange rate through the system. An effective exercise is to calculate the steady state nitrate-N balance assuming some water exchange rate through the system. Nitrate-nitrogen is relatively non-toxic to fish and as such will not influence the controlling flow rates in the system. One can choose some value such as 500 mg/L if you want a number to work with.



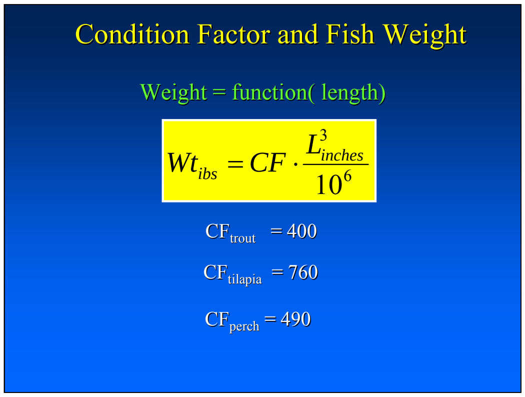
The premise of RAS design is that we are endeavoring to grow fish at some defined rate, and that rate then defines the required fish feeding rate. The fish feeding rate in turn then defines waste generation loads and oxygen consumption. A convenient way of defining fish growth is based upon a temperature unit approach and some defined number of temperature units to create a unit growth rate, e.g., one inch per month

$$\text{Growth (inches/month)} = [T - T_{base}]/\ TU_{base}$$

The above equation predicts growth based with units of inches per month. The T_{base} and TU_{base} terms are defined in the above and based upon historical observation and analyzing hatchery records. The terms for trout are from Piper et al. (1982) and the tilapia and perch terms are from the author's unpublished data:

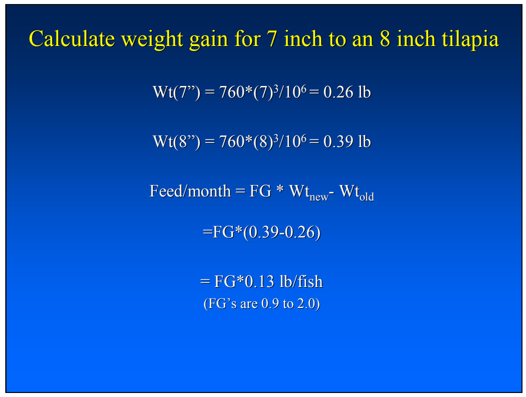
The above equation is subject to the limitation that if T is greater than T_{max}, then calculate the growth at T_{max}.

Note that excessive temperatures will compromise growth and/or feed conversion.



The weight of fish can be mathematically related to their length by using a term called the condition factor (CF); the bigger the CF, the more weight per unit length. For a given length, the bigger the CF, then more the weight of a particular fish. Each fish species will have an associated CF value to describe expected or normal body condition

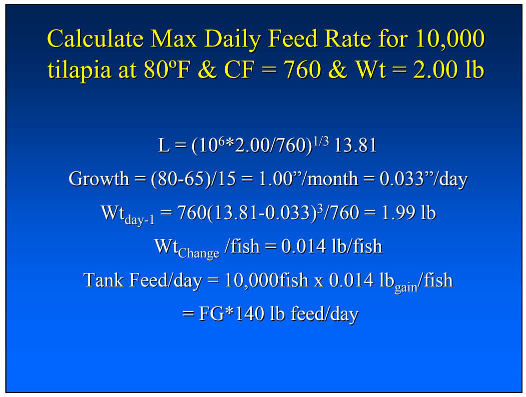
The CF values will become stable at an early fingerling stage, certainly above 2 or 3 inches in fish length. The CF value is an EXCELLENT way to monitor over and under feeding. Are your fish too fat or too thin---check their condition factor. Monitoring fish growth by rate of length increase is also a very appropriate way to monitor growth. Length growth should remain constant from fingerling stage all the way to market size.



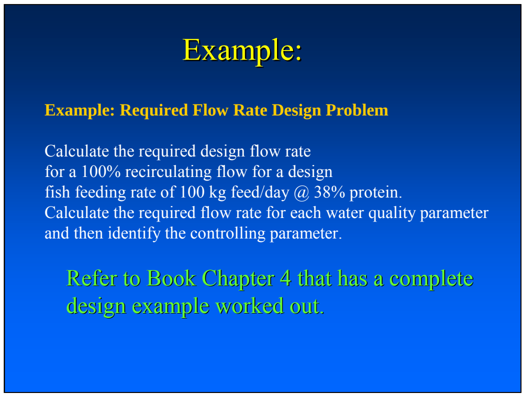
Now, we can calculate actual gain by calculating the weights associated with two specific fish lengths over the time period required to achieve this growth. In the previous example, we grew 7 inch tilapia for one month at 80°F, which produced one inch of growth to a size of 8 inches

FG is the Feed to Gain ratio. Note that feed is approximately 5 to 7% moisture and fish mass gain is approximately 75 % moisture. So on a dry matter basis, then $FG_{dry\ matter} = FG_{wet} * (100\%-5\%)/(100\%-75\%) = FG_{wet} * 3.8$

Remember, all the "P" terms in the mass balance equation are related to the feeding rate term. Essentially, all design aspects of RAS technology are related to or in fact are based upon the daily design feeding rate. The daily design feeding rate is the critical value needed in designing a complete RAS. It should make some intuitive sense then, that one must calculate the largest anticipated feeding rate in order to properly design the water conditioning components of an RAS. And when will this largest feeding rate occur? The answer being when the fish tank reaches its largest biomass and associated fish mass. This is also where many designs fail, since the largest fish mass and largest feeding rate is the most stressful condition on the RAS. Any of the individual water quality parameters can quickly become the defining variable for water quality control, meaning the water flow rate through a particular water conditioning design component is not sufficient to remove the generated pollutant load, e.g., CO_2 removal device. The water parameters always come to an equilibrium based upon a balance between production load, water flow rate and change in concentration for different water quality variables across the conditioning components. The challenge to the designer and manager is to make sure these equilibrium values at least as "good" as the design target values for these variables.

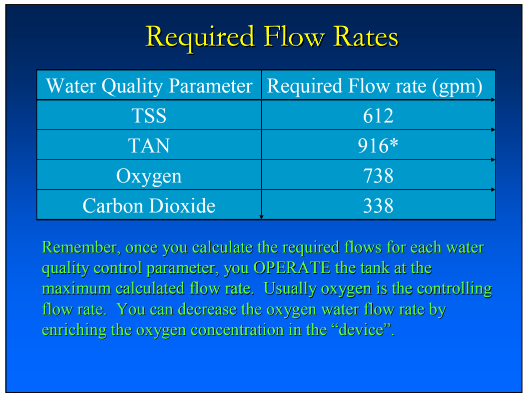


Now you have "arrived" !!! This is the number you are looking for since it will be the maximum feeding rate achieved in the tank. All your water conditioning equipment and water quality control will be based around this, yes THIS, key number. Note that mathematically, you only achieve the maximum loading capacity for your tank on the last day of growth. This suggests that you will want to think of ways to utilize the full water conditioning capacity of your system, e.g. multiple tanks with different cohort class sizes on the same biofilter system. This increases design and management complexity (read potential for failure) but will maximize the economic potential of your system.



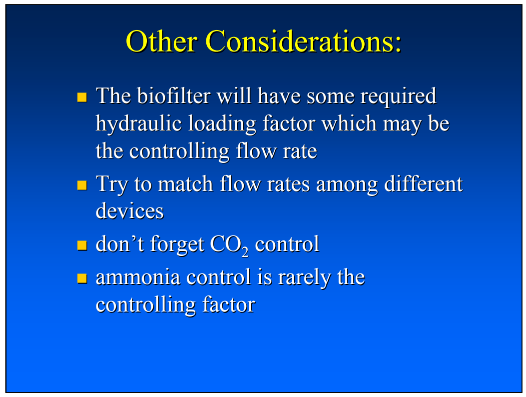
Example: Required Flow Rate Design Problem

Calculate the required design flow rate for a 100% recirculating flow for a design fish feeding rate of 100 kg feed/day @ 38% protein. Calculate the required flow rate for each water quality parameter and then identify the controlling parameter.



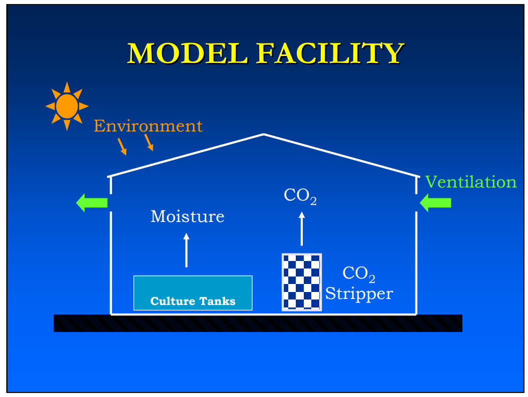
Water Quality Parameter	Required Flow rate (gpm)
TSS	612
TAN	916*
Oxygen	738
Carbon Dioxide	338

Remember, once you calculate the required flows for each water quality control parameter, you OPERATE the tank at the maximum calculated flow rate. Usually oxygen is the controlling flow rate. You can decrease the oxygen water flow rate by enriching the oxygen concentration in the "device".



The only footnote to the above is that you must also calculate the required hydraulic loading for the biofilter as in m3/hr/m2 (gpm/ft2). This may become the controlling flow rate over and above the flow rates required to maintain water quality conditions. Finally, just remember that if such were the case, it simply means that the equilibrium concentrations for all the water quality parameters would be just a little *better* and the fish will never complain about that.

The carbon dioxide control options considered in the computer model include packed tower stripping, addition of sodium hydroxide, dilution through water exchange, in-tank and side-stream surface aeration, and in-tank and side-stream diffused aeration.



The model facility employed in the computer model is shown schematically here. The culture tanks are housed indoors and the CO_2 removal device is venting directly to the airspace. The important process flows include carbon dioxide, moisture, and heat.