Flow rates through our filters, do they matter?
(as they relate to ambient ammonia in the pond)

By Spike Cover, May of 2006

Summary

In answer to the question posed by the title, yes they matter. Ammonia is a toxin and can cause fish death. Chronic sublethal levels can result in growth suppression and increased susceptibility to disease. Flow rate through the bio-converters (filters) and feeding rate are the two main determinates of ambient ammonia in a clean pond. As the flow rate goes up, the ambient ammonia comes down and as the feeding rate goes up, so does the ambient ammonia. Big ponds reduce ammonia spikes, big filters allow for higher feeding rates and automatic feeders allow the ammonia produced to be "leveled" over the day. The pH and, to a lesser extent, the temperature of the water effect the fraction of unionized ammonia, the most toxic form of ammonia. Raising either raises toxic ammonia. A good rule of thumb is that it takes about 60 gpm thru adequate bio-converters (filters) to process the ammonia produced by feeding one pound of food per day. Increasing the flow rate through existing bio-converters (filters) will almost certainly improve water quality. See complete article below.

We know ammonia is not good for fish. Ammonia is a toxin and high levels can burn the gills, the skin and the gut and can even cause death. Chronic sublethal levels of ammonia can result in adverse effects including growth suppression and increased susceptibility to disease. Thus, we can easily conclude that it would be in our interest to know how much of this toxic substance is in our pond water and how we can influence its removal to make a better environment for our koi.

In an attempt to get a handle on this subject, let's answer three questions:

Question #1: What limit for maximum ammonia should we seek to achieve?

We have all been told that the ammonia in our ponds should be zero. But we also know that the fish are always producing ammonia and that the filters could not possibly eliminate it instantly so there must be some in the water. How do we reconcile this apparent contradiction? When you hear that the ammonia should be zero, what the speaker is generally referring to is the fact that most common (inexpensive) test kits cannot measure ammonia below 0.1 ppm and many not below 0.25 ppm and that keeping the ambient ammonia below this level is desirable.

To make things a bit more complicated, most tests don't really measure ammonia, they measure total ammonia nitrogen, or TAN. This is the nitrogen associated with the various forms of ammonia. The two forms that concern us here are unionized ammonia (the toxic form) or NH_3 and ammonium, the ionized form (the much less toxic form) or NH_4^+. We, however, are most concerned with the more toxic form, the ammonia or NH_3.

If we want to know the amount of ammonia that could be represented by a given TAN reading, we would need to ratio the atomic weights of ammonia and nitrogen to obtain that value. So with N = 14 and H = 1, $NH_3 \div N = (14 + 3) \div 14 = 1.21$. This means that if we multiply the weight of the TAN by 1.21, we obtain the equivalent weight of ammonia. By a similar process, if we take the ratio of the molecular weight of ammonium divided by that of nitrogen, we obtain 1.29 which is the factor to convert TAN to ionized ammonia or ammonium.

The aquaculture folks suggest a value for max ammonia. From Michael Timmons' book, *Recirculating Aquaculture Systems, Second Edition*, we have the following:

AMMONIA

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 (NH_3 or $A_{NH3\text{-}N}$).

But this is for aquaculture and it would likely behoove we hobbyists to set a more stringent limit as we seek a better environment than merely adequate. With this in mind, I propose that we set a limit 1/10th that set by the European Inland Fishery Advisory Commission, i.e., we will use 0.0025 mg/L as the maximum allowable average un-ionized ammonia nitrogen in our ponds.

Question #2: How much ammonia is in the pond water?

Scientists have observed the proportion of ionized and unionized ammonia in water based on pH and temperature and have produced charts and tables that show these various proportions. Wheaton in his book, *Aquacultural Engineering* (p. 561), provides his Figure 13.57.

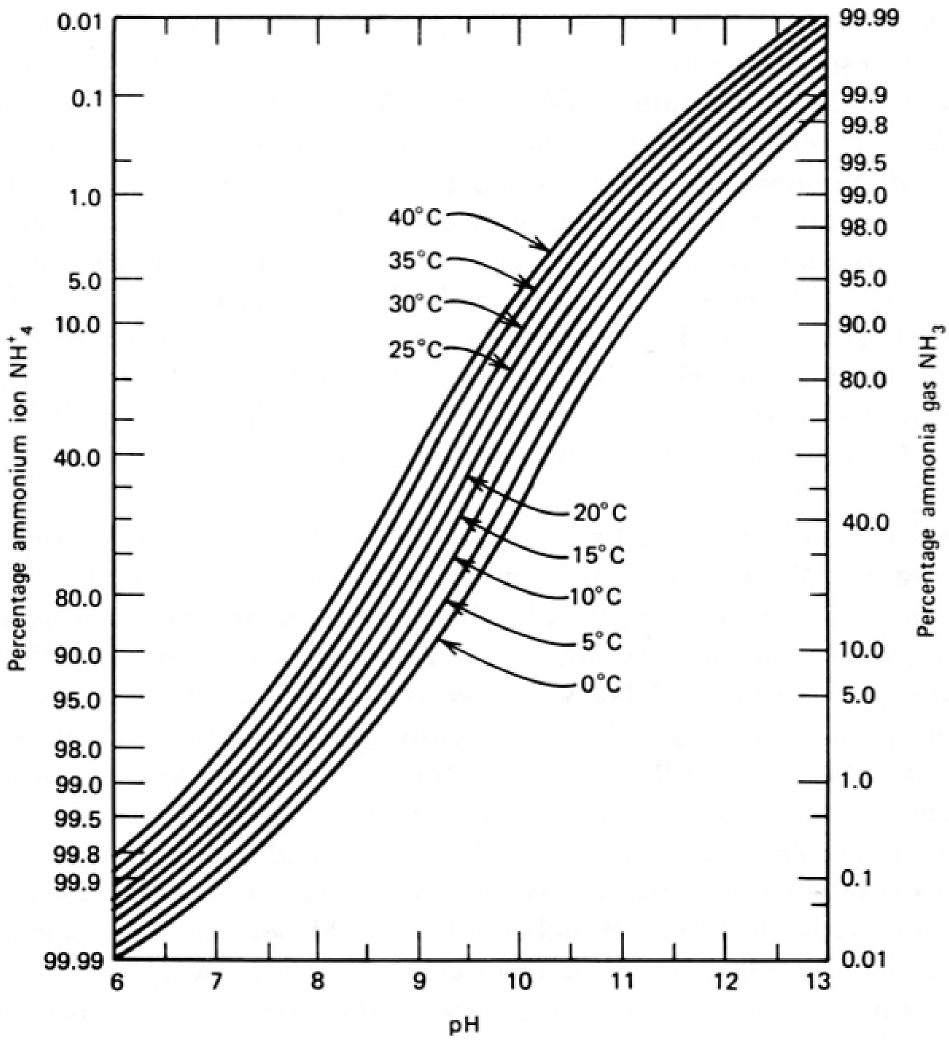

Figure 13.57 Effects of pH and temperature on the distribution of ammonia and ammonium ion in water. Data from Liao et al. (1972).

And for those who are more comfortable with tables, there is Table 2.5 from Michael Timmons' book, *Recirculating Aquaculture Systems, Second Edition*.

Table 2.5 Percentage of Free Ammonia (as NH_3) in Freshwater at Varying pH and Water Temperature, (Spotte, 1979)

pH	10°C (50°F)	15°C (59°F)	20°C (68°F)	25°C (77°F)
7.0	0.19	0.27	0.40	0.55
7.1	0.23	0.34	0.50	0.70
7.2	0.29	0.43	0.63	0.88
7.3	0.37	0.54	0.79	1.10
7.4	0.47	0.68	0.99	1.38
7.5	0.59	0.85	1.24	1.73
7.6	0.74	1.07	1.56	2.17
7.7	0.92	1.35	1.96	2.72
7.8	1.16	1.69	2.45	3.39
7.9	1.46	2.12	3.06	4.24
8.0	1.83	2.65	3.83	5.28
8.1	2.29	3.32	4.77	6.55
8.2	2.86	4.14	5.94	8.11
8.3	3.58	5.16	7.36	10.00
8.4	4.46	6.41	9.09	12.27
8.5	5.55	7.98	11.18	14.97

If we pick somewhat “high normal” parameters to use for an example, we can likely bias our results toward the conservative. So let’s choose a pH of 8.0 and a temp of 75° F, where we see that the amount of ammonia (NH_3) is about 5%. Remember this 5% number.

There seems to always be a disproportionate amount of attention applied to nitrification and ammonification. All these calculations depend upon the estimate of an ammonia generation load, which is based upon the fish feeding rate:

$$P_{TAN} = \frac{F \cdot PC \cdot 0.092}{t = 1\ day} \qquad (4.9)$$

The constant in the ammonia equation is based upon a series of approximations and estimates that when multiplied together result in the 0.092.

$0.092 = .16 \cdot .80 \times .80 \cdot .90$

- 16% (protein is 16% nitrogen)
- 80% nitrogen is assimilated
- 80% assimilated nitrogen is excreted
- 90% of nitrogen excreted as TAN + 10% an urea (fresh water fish only)
- all TAN is excreted during time period "t"
- non assimilated nitrogen in feces is removed quickly
- (no additional mineralization of nitrogenous compounds)

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.

In Timmons' equation 4.9 above, P_{TAN} is TAN production by fish in kg/day; F is feeding rate in kg/day, and PC is protein concentration as a decimal fraction.

We now proceed to how much ammonia is generated over what period of time. Once again, aquaculture provides a way to the answer. If we have koi food with a protein content of say 36%, and we use the (conservative) 10%of that, suggested by Timmons, to estimate the TAN that is emitted into the water from the fish, we have 3.6% of the weight of the feed fed that turns up as TAN in the water. But we know that not all the TAN is ammonia. If we go back to our assumptions that resulted in only 5% of the TAN being NH_3-N, we can conclude that only 5% of the 3.6% or 0.18% of the feed results in NH_3-N in the water.

Thus if we feed one pound of food per day, it will result in 0.18% of one pound toxic NH_3-N. That is equal to 0.0018 pounds of NH_3-N or 0.817 grams or 817 mg of NH_3-N per day. Remember this number too.

Question #3: How can we keep the average NH_3-N under 0.0025 ppm?

Here we will need to make the assumption that water running thru the filtration system will be totally cleaned of both forms of ammonia – not always the case but we'll address that later in the Discussion section. With that assumption, we can determine how much clean water must the 817 mg/day of ammonia be diluted into to bring the concentration of NH_3-N down to our desired limit of 0.0025 ppm. For this we go to the simple equation that:

Concentration = Solute ÷ Solvent, where the solute is the NH_3-N and the solvent is clean water.

Rearranging the equation we get: Solvent = Solute ÷ Concentration

Substituting our chosen values yields:

Solvent = 817mg/day ÷ 0.0025mg/L = 326,800L/day

or, 86,275 gallons/day = 3535 gal/hr or about 60 gal/min

So this means that if we have a pH of 8.0 and a temperature of 75° F, have adequate bio-conversion and want to feed a pound of food per day and keep good water (average ambient NH_3-N less than 0.0025 ppm), we will need a flow rate of about 60 gpm or greater thru our filters to achieve this.

Using this same methodology, it is possible to calculate the minimum flow rate in GPM through 100% effective bio-converters required to produce 0.0025 or less of average ambient NH_3-N when feeding one pound of koi food per day for various values of temperature and pH.

Discussion

First, it is important to remember that this analysis assumes no other major sources of ammonia are in the pond other than the fish. If this is not the case, e.g. a very dirty pond with rotting organic material adding significantly to the ammonia, then all bets are off.

It is also important to remember that these calculations are for a feed rate of one pound of food per day. So if twice that amount is given, the required flow rates need to be doubled; if ½ that amount is given, the required flow rate is cut in half; etc., etc. Note that these flow rates only relate to ammonia. Other parameters such as total TAN or dissolved oxygen may require higher flow rates.

As an example, Timmons gives a rule of thumb that TAN for warm water fish should not exceed 2 to 3 ppm. If we choose the lesser of these values, again reduce it by a factor of 10 and recalculate the minimum flow rates to process one pound of food per day, we determine that 15

GPM will set a higher value for some of the flow rates otherwise calculated by the previous assumptions.

It is often suggested to stop feeding the fish when disease strikes a pond. We can now see how this can improve water quality especially if the flow rate thru the bio-converters remains the same.

It is always good to check theory against reality. And once again the aquaculture folks provide some perspective in the form of empirical data. From Timmons' *RAS*, we have Figure 7.2.

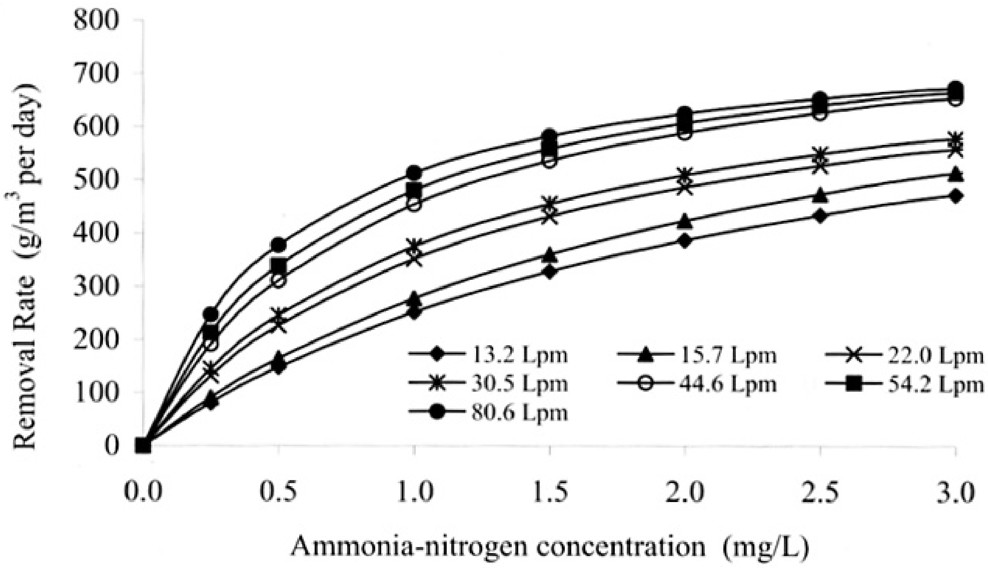

Figure 7.2 Rates of Nitrification as Affected by Water Column Concentration for a Bubble-Washed Bead Filter (Ebeling, 2000).

The effect of flow rates on ammonia removal can be better seen by re-plotting some of the data in Timmons' Figure 7.2 into Figure A shown below.

On page 575 of Wheaton's book where feeding and ammonia as they relate to raceway fish farming are being discussed, it says,

> They have also shown that ammonia levels in the water are directly related to the amount of food fed and the water inflow rate but not to the volume or rate of water change in the raceway.

Wheaton makes the statement that the ammonia levels are NOT related to the volume or turn-over rate of a system. This seems counter intuitive. How can it be that a big volume of water (pond size) has little or nothing to do with diminishing the ambient ammonia in the water? The answer is that when we refer to ambient ammonia, we are really referring to the "average" ambient ammonia and also, in this analysis, we are discounting the nitrifying capacity of the pond walls and bottom. Big water volumes can and do dampen ammonia spikes and are particularly helpful in this regard when the fish are fed only once or a very few times a day. But over time, an equilibrium is reached where, on average, the amount of ammonia generated per day is equal to the amount of ammonia removed per day. This must mean that the total volume of water "cleaned" by the filter had to contain the average amount of ammonia generated each day. And that means that the total ammonia generated divided by the total volume of water cleaned is equal to the average ambient ammonia. So in general, the more flow through the filters, the more clean water that is produced and the less average ambient ammonia that remains in the water.

Getting back to the number of feedings per day, we look again what the aquaculture folks say (from Timmons):

> Equation 4.9 represents a conservatively high estimate of the P_{TAN} production rate. We use the time period in Eq. 4.9 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.

So we see that if we feed only once daily and use the four hour period suggested by Timmons, that will increase the short term or transient ambient ammonia above the 24 hour average ammonia by 24hr/4hr or by about six times. Now we can see that setting our original limits 10 times better than those suggested by aquaculture was probably a good choice and it still also provides some margin for varying pH, temperature and inefficient bio-converters.

Please don't think that if you have a 10,000 gallon pond and a filter the size of a breadbox, that you can increase the flow through the breadbox to near sonic velocity and have it do the job. It won't happen. It does, however, mean that if your are currently using the old rule of thumb and have the flow rates thru your up-flow rock-gravel-and-sand filters set at 1.5 to 2.0 gallons per square foot (of filter surface area perpendicular to the flow), and you increase the flow rate by 50%, you will almost certainly lessen the average ambient ammonia in your system. "It's a good thing." (M. Stewart, circa 2000).

For those seeking to lower the ambient ammonia in a pond, the above analyses and discussion make the case for employing the following:

Higher than “normal” flow rates through filters,
Very effective filters,
Big ponds, and
Many feeds per day (auto-feeders)

Please use this along with other criteria when sizing system components and be sure to provide some margin for “off target” parameters. Ponds (and fish) are not one dimensional.

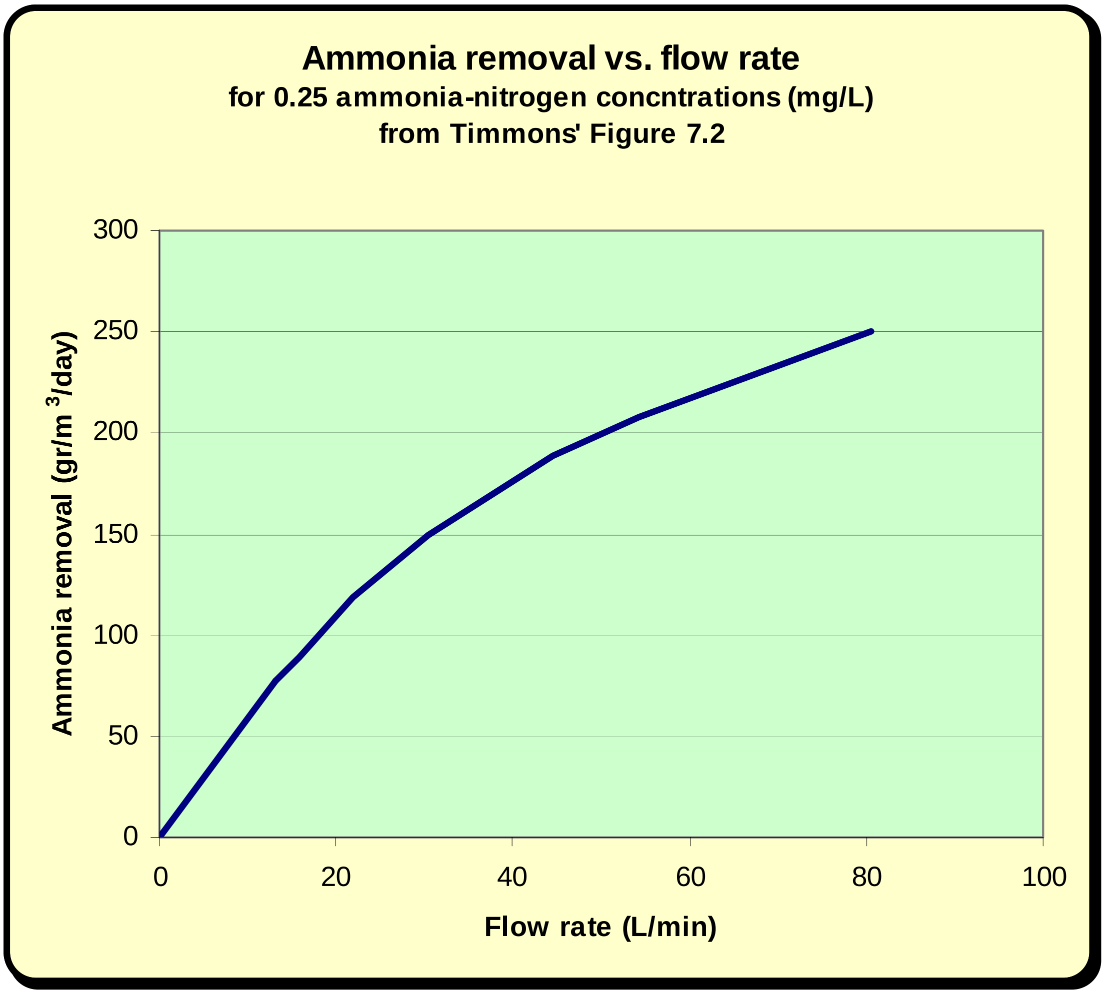

Figure A

Bottom line: Increasing the flow rate through existing bio-converters (filters) will almost certainly improve average water quality and spreading the feedings out over the day will lessen transient ammonia spikes. (But, hey! Who says we need less spikes?!!!)

Acknowledgements: I would be remiss if I did not recognize Gerry Preston for his article "Filtration Desimplified" in NI about 10 years back. That article inspired me to further explore this subject. (And, his retirement from the hobby was a loss to us all.) Also my thanks to (in alpha order) Burt Ballou, Duncan Griffiths, Jack Marrin and Chris Neaves for being kind enough to review and comment on drafts of this article.

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