FAQ: AQUARIUM FILTRATION

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Summary
This article describes how filtration can help ensure a healthy aquarium. The first half describes what filters are, and how they work. The second half evaluates the different types of filters.

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1. Why you need Filtration

Sometimes we forget that fish kept in an aquarium are confined to a very small quantity of water as compared to their natural habitats in the wild. In the wild, fish wastes are instantly diluted. But in an aquarium, waste products can quickly build up to toxic levels.

These waste products include ammonia released from your fishes' gills, fish poop, and scraps of uneaten food. The food and the poop will also eventually decay, releasing ammonia. Even small amounts of ammonia will kill your fish.

Obviously, the more sources of fish waste, the quicker and greater the ammonia problem. A small heavily-fed tank with lots of large fish will have much more ammonia than a large tank with one seldom-fed small fish. But for both these cases you need some form of aquarium filtration to control the toxic ammonia.

Some aquarists try to control ammonia levels exclusively by changing the water. This is helpful, but impractical because of the frequency and size of the water changes required. Fortunately, there is an easier way! In fact, the world is full of bacteria that want nothing more than to consume the ammonia and convert it into less toxic substances. For many an aquarist, this process occurs without their knowledge or help. However, the smart aquarist will learn how to take advantage of this beneficial bacteria by maximizing its growth.

When you start a new fish tank, colonies of beneficial bacteria have not yet had the chance to grow. For a period of several weeks this is hazardous to fish. You must gradually build up the source of ammonia (i.e., start with only one or two small fish) to allow time for the beneficial bacteria to grow. This is called ``cycling" your tank. Read more about this in the BEGINNER FAQ.

Remember that the bacteria break down the ammonia into substances (first nitrate, then eventually nitrate) that are merely less toxic, rather than non-toxic. Many fish can tolerate reasonably high levels of nitrates, but over time the nitrates will accumulate until they, too, become toxic. Also, because nitrate is a fertilizer, high nitrate levels can lead to excess algae growth.

Water changes

Although there are many ways to remove excess nitrate, the most effective way is to regularly change part of the water. _This is one of the most neglected and important parts of aquarium maintenance!_ How often and how much you need to change depends a lot on the waste load in your tank, and the sensitivity of your fish. You don't want to change _ALL_ of the water at any point in time because the change in water chemistry will be stressful to your fish. The best way to decide how often and how much to change your water is to monitor your water quality with water tests. As a minimum, if your tank is new, you should test for ammonia and perhaps nitrite. In established tanks you should monitor for nitrate accumulation. Read more about water tests in the TEST KIT SECTION of the BEGINNER FAQ. Water tests are the most reliable way to know how well your aquarium filtration works.

For an average tank, you should change no more than one third of the water in 24 hours. Many aquarists with average aquariums change a quarter of the water every two weeks. Your aquarium is probably not average, and you really should measure nitrate levels to determine your water change schedule.

Biological filtration

Biological filtration is the term for fostering ammonia-neutralizing bacteria growth. It is so important to the health of your aquarium that we should look at how this process works more closely. (There are other types of wastes that can cause problems, but the regular partial water changes needed to control nitrates are typically enough to control other forms of waste as well.)

Mother Nature provides several types of bacteria that break down ammonia into progressively less toxic compounds. First, _nitrosomonas_ breaks ammonia into nitrites. Then _nitrobacter_ breaks the nitrite into nitrate. These bacteria are not harmful and are quite abundant in nature. They are so common that we do not need to add them to our aquariums; nature does it for us.

In the presence of ammonia and oxygen these bacteria will naturally multiply. The bacteria attach to the tank, rocks, gravel, and even tank decorations. Note that we have not yet said anything about a physical filter. This is because biofiltration bacteria require only

1. A surface upon which to attach,
2. ammonia for food, and
3. oxygen-rich water.

This sounds so simple; why do we need a physical filter?

Actually, if you limit the amount of fish to what the natural biofiltration can handle, you do not need a physical filter. Unfortunately, you cannot support very many fish with only the natural biofiltration.

In the last few decades, the hobby has seen many new types of biological filters invented which can vastly increase the capacity of the bacteria colony to provide biological filtration to your aquarium. In essence, all of these types of filters provide additional surface area for bacteria attachment and increase the available oxygen dissolved in the water.

Mechanical filtration

Remember that ammonia comes directly from the gills of your fish, but also from decaying fish poop and food scraps. If you can mechanically filter out the poop and the waste food before it gets a chance to decay, you can be a step ahead in the game. Not to mention that these wastes are ugly and can detract from the beauty and enjoyment of your aquarium.

Simply stated, mechanical filtration is the straining of solid particles from the aquarium water. Mechanical filtration does not directly remove dissolved ammonia. Most common mechanical filter media do not remove microscopic bacteria and algae from the water. Neither will mechanical filtration remove any solids trapped by gravel, plants, or decorations.

You will need another method to remove the solid wastes from the nooks and crannies of your aquarium. One of the easiest methods is to ``vacuum" the gravel, etc., as part of your regular water change routine and everybody should do this. (Note that those marine aquariums which use ``live substrates" are an exception.) Some people install circulation pumps, known as wave makers, to improve the chance of catching solid wastes in the mechanical filter.

The four most popular mechanical filtration media are sponges, paper cartridges, loose and bonded floss media which are reusable to different degrees. Clean paper cartridges have the smallest openings and clean bonded floss has the largest openings. Clean sponges and clean loose floss fall somewhere between.

A filter media with small openings catches finer particles, but clogs faster. Also, as a rule, a physically large filter area will clog more slowly than a small filter. As the filter media gets dirty it will trap smaller and smaller particles. At some point the media is so clogged that it will not pass water.

SUMMARY: A good mechanical filter is one that traps enough solids to keep the water clear without plugging too often.

Chemical Filtration

Chemical filtration, in short, is the removal of dissolved wastes from aquarium water. Dissolved wastes exist in the water at a molecular level, and fall into two general categories, _polar_ and _nonpolar_. The most common chemical filtration method involves filtering the water through gas activated carbon which works best on the nonpolar wastes (but also removes polar wastes). Another effective method is _protein skimming_, which removes polar wastes such as dissolved organics.

Granular activated carbon (GAC) is manufactured from carbon, typically coal, heated in the presence of steam at very high heat. This process causes the carbon to develop huge numbers of tiny pores, which trap nonpolar wastes at the molecular levels by means of adsorption and ion exchange, and removes heavy metals and organic molecules, which are the source of undesirable colors and odors, through a process known as molecular sieving.

The best GAC for filtering water is made from coal and is macroporous (having larger pores). A good macroporous activated carbon feels light (not dense) and fizzes and floats when initially wetted. GAC intended for removing wastes from air (such as odors) are commonly made from coconut shell and are microporous. Carbons for filtering air feel more dense.

Some people (especially those with reef aquaria) are concerned about phosphate leaching from activated carbons. As a rule, buy only carbons made by reputable aquarium supply companies which have been acid washed during manufacture to minimize ash content. Carbons low in ash also help reduce the chance of undesirable pH shifts. Low ash carbons typically have lower phosphate leaching levels too.

The phosphate in GAC stems from the fact that activated carbon is manufactured from coal, which was once living plant matter. All living matter is high in phosphates. The leaching of phosphate from GAC is known to be high initially and to decrease over time. This problem can be mitigated significantly by presoaking your activated carbon for a few weeks before use.

Some people are concerned about GAC removing trace elements required by plants and invertebrates for healthy growth. Trace element depletion is a problem in planted aquaria and minireefs, with or without activated carbon. The potential benefits of activated carbon are great enough that on whole you will be better off using it. If trace element depletion is a worry, use a trace element supplement in conjunction with the activated carbon.

GAC cannot be rejuvenated outside a laboratory, but fortunately, it is cheap enough to use liberally. Always wash your carbon before use to remove the dust that accumulates during shipment. Advice on how much to use vary, but smaller amounts changed more frequently seem to work best. You probably want to experiment, but 1/2 cup per 20 gallons water, changed monthly is a good starting point. In summary, activated carbon is an excellent, cheap and effective filtration method which is highly recommended for all aquaria.

A variety of special chemical filtration media have been developed to remove specific chemicals. A common one is made from the zeolite clay (also used as some cat litters), and is marketed under such brand names as ``Ammo-Carb". This media removes ammonia from water, and is good for short term use. The aquarist should be aware that if zeolite is used, especially when cycling a new aquarium, then the establishment of natural biological filtration will be delayed or disrupted.

Protein skimmers are primarily used in saltwater aquaria, especially reefs. They have the remarkable ability to remove dissolved organic wastes before they decompose. The process involves taking advantage of the polar nature of the organic molecules, which are attracted to the surface of air bubbles injected into a column of water. The resultant foam is skimmed off and discarded.

2. FILTER TYPES

The humble corner filter

For decades, hobbyists have successfully kept fish healthy and happy through the use of the $2.49 corner filter. Typically, they are clear plastic boxes, which sit inside the tank. An air stone bubbles air through an air lift tube, which forces water through a bed of filter floss or other media. mechanically filtering the water. Colonies of bacteria build up on the media, providing excellent biological filtration. (It is important to change only some of the media at any given time! This way the bacteria does not get wiped out.) Nowadays people don't use corner filters as much because they're ugly, take up space in the tank, and require a bit more frequent maintenance than other filters. But you can't beat the price.

Another use of the corner filter, that is not really matched by other filter types, is as an impromptu quarantine tank filter. If you have the need to set up a second tank on the quick, you can take some gravel from an established tank and put it in a corner filter, and immediately, you will have a functioning biological filter. This way you can turn a five gallon bucket into a quick and cheap hospital/quarantine tank on a moment's notice.

Undergravel Filters

Fish stores commonly sell undergravel filters (UGF's) to beginners in ``aquarium kits" because they are cheap, and they work (for a while). UGF's work by slowly passing water through the bottom gravel, which sits on top of a perforated plate. The water can be pumped with an air lift, with bubbles air lifting the water in a vertical tube attached to the filter plate. Also, some people prefer the increased water flow achieved with submersible pumps, called powerheads, attached to the same lift tubes.

UGF's make good biological filters, because the slow flow of water through the gravel fosters large colonies of beneficial bacteria which neutralize toxic ammonia. The hitch is, that UGF's are awful mechanical filters. Fish waste gets pulled out of sight into the gravel. Before you know it, the gravel clogs up. You then have a big mess and a health risk to your fish!

A partial solution to this dilemma is to run the powerhead in reverse, sending water _up_ through the gravel. This technique is known as _Reverse-flow Undergravel Filtration_ (RUGF); conversion kits or special powerheads can be purchased to accomplish this. The intake of the powerhead is covered with a porous sponge which serves to "prefilter" out some of the waste that can clog the gravel. In actually practice, this helps, but is only a partial solution.

If you choose to use an UGF/RUGF, you must regularly _vacuum your gravel_. Fish stores sell siphon hoses with a ``wide mouth gravel vacuum tube" attachment that ``washes" the gravel during your regular water changes. _IF_ you clean your gravel regularly, and maintain a regular and frequent partial water routine, UGF's and RUGF's are an economical and effective aquarium filter in freshwater aquariums, and in lightly stocked saltwater fish-only aquariums

Sponge filters

Sponge filters provide an efficient and cheap form of biological filtration. Water is forced through a porous foam, either by a powerhead, or air bubbling through an airlift tube. Water flowing though the sponge allows the growth of a colony of beneficial bacteria which neutralizes toxic ammonia.

One style of sponge filter uses two sponges attached to one lift tube. These have the advantage that the sponges can be cleaned one at a time, reducing bacterial loss. Also, one of the sponges can be removed and transferred to a new tank, bringing with it a colony of beneficial bacteria, and thereby "jump starting" the cycling of a new tank. Some enlightened fish stores sell these double sponge filters to beginner customers when they sell a tank kit. They take one of the new sponges out of the "box" and swap it for a old established sponge in one of their tanks in their store which is carried home in a plastic bag.

Power filters

Most people agree that power filters are much easier to maintain and can be as economical as undergravel filters. There are many styles of power filters, but the most common hangs on the back of the tank. A siphon tube pulls water from the tank into the filter box and passes the water though a mechanical filter (typically a porous foam sponge). The sponge doubles as a biological filter. A internal pump then returns the filtered water into the aquarium. These power filters come in many sizes suited for small to large aquariums.

The foam sponge can be easily inspected for clogging or removed for cleaning. You must clean the sponge regularly to remove the solid wastes before they decompose and dissolve back into the water. It is quite important that when you clean the porous foam that you do not kill the bacteria colony through the use of detergents, very hot or very cold water. A safe and easy way is to rinse the foam sponge in the bucket into which you have just drained some tank water during your regular water change routine.

Power filters now come with all sorts of fancy ``features". Most allow placement of a chemical filtering media, typically granular activated carbon, in the water path.

Another development in the last few years is the ``wet-dry wheel" (called a _biowheel_ by one manufacturer). The beneficial bacterial colonies that neutralize toxic ammonia require an oxygen rich environment to grow. The ``wet-dry wheel" passes water over a water wheel device which sits outside (on the edge) of the aquarium. This rotating wheel maximizes available oxygen allowing a large bacteria colony to flourish. One drawback is that these wheels have been known to jam, so you need to check them frequently. Other than this minor point, the ``wet-dry wheel" is an excellent method of providing vigorous biological filtration.

The Canister filter

Canister filters have some similarities with the ``hang on tank" style of power filters, but the essential difference is that canister filters are designed to provide more powerful mechanical filtration. Typically, the water is pumped, at moderate pressure through a filter material, such as glass wool, or a micron filter cartridge. Canister filters are especially useful in aquaria with large or numerous messy eaters that generate a lot of waste. For these filters to be effective they must be frequently cleaned, to avoid the decomposition of waste in the water stream.

These filters usually sit on the floor below the tank, but also can hang on the tank, and in some designs even sit inside the tank, in which case they are called a ``submersible filter". Some hobbyists attach a ``wet-dry wheel" to the outflow of their canister to improve the biological filtration capacity of this type of filtration system.

Wet/Dry Filters

Also known as trickle filters, wet/dry filters work on the principle that the beneficial colonies of ammonia neutralizing bacteria grow best in the presence of well oxygenated water. By ``trickling" water over unsubmerged plastic gizmos or other media, wet/dry filters provide a very large air/water surface area. They come in many shapes and sizes. The boom in successful saltwater aquariums in the 1980's can be attributed to the use of this filter type.

Many things can used for the media, with the best providing great amounts of surface area, while at the same time having large openings to reduce the tendency to clog and ensure efficient gas exchange. The problem of clogging of the media can also be reduced by prefiltering the water with an efficient mechanical filter, and (when used) with a protein skimmer.

Protein skimmers (aka Foam Fractionators)

Protein skimmers were initially developed for use in industrial sewage treatment plants where they are also known by the term _foam fractionator_. Protein skimmers have the unique ability to remove _dissolved_ organic wastes _BEFORE_ they decompose! This is a neat trick which is accomplished by taking advantage of the fact that organic chemicals are attracted to the surfaces of bubbles which are passed in large numbers through a column of water. The foam is then ``skimmed" off the water, while at the same time removing the organic wastes. The foaming process only works in a water with high pH and salinity, and as a result skimmers are primarily for saltwater use.

The protein skimmer is largely responsible for the boom in reef aquaria in the 1990's, due to the high water quality possible with this type of filtration. A current ``state of the art" in reef systems is based upon the use of protein skimmers and live rock without the use of a wet/dry filter. This school of thought is known as the ``Berlin method".

Fluidized bed filters

Very recently, some hobbyists have reported success with a new type of filter which uses a fluidized bed of sand. This filter is roughly similar in principle to the reverse flow undergravel filter, but with much higher water flow. The higher water flow keeps the sand clean of debris, while at the same time allowing the development of large and efficient colonies of beneficial bacteria. Reported problems include oxygen depletion and clogging.

Denitrators

Another specialized type of filter is designed to help in the control of the accumulation of nitrates, the end product of the neutralization of ammonia by the biological activity of bacteria. These fall into two categories, the anoxic bacterial, and the plant/algal scrubbers (discussed in the next section). It has been discovered that colonies of bacteria which grow in oxygen poor environments can be harnessed to biologically consume nitrate, and release harmless nitrogen gas. This method is achieved in one of two ways. The process was first developed in the 1980's through the use of a box system, coil, or porous foam block which allowed very slow transmission of nitrate-laden water. Inside the box/coil/foam, sugar was placed, and the slow passage of water quickly became anoxic. In these anoxic conditions, bacteria would grow and consume excess nitrate. Many aquarists have reported failure in their attempts at this type of filtration.

More recently, hobbyists have developed similar anoxic conditions below plates at the bottom of their tanks buried in fine sand. In the saltwater systems, these sand beds are referred to as "live sand". In freshwater planted systems, fine grain substrates are allowed to develop anoxic zones which probably also have a denitrification capability.

The Berlin Method of reef aquariums involves the use of large quantities of live rock harvested from tropical reefs. Aquarists report good nitrate control in live rock systems, which, though not well understood, probably involves the denitrification of the nitrates within the interior of the rocks. Another school of thought is that the heavy growths of calcareous algae on the live rocks in Berlin Method reef aquariums consume nitrate.

Algal Scrubbers

Algal scrubbers use live algae to do the ``filtration". Water is run over a wire mesh in a trough under bright lights, where algae is encouraged to grow. The growth of the algae removes some pollutants from the water. This is a controversial form of filtration for reefs and large marine ecosystems invented by Dr. Adey at the Smithsonian. Some believe it is a complete filtration solution, others claim its use leads to poor water quality and algae growth in the tank as well. In freshwater planted aquariums vigorous plant growth has been observed to beneficially consume excess dissolved nitrates.

Chillers

While not really a filtration, saltwater aquarists occasionally have the need to lower the temperature of their aquarium water. The high light levels needed in reef aquaria involve a build up of excess heat. Use of a hood fan and removal of the ballast from the vicinity of the tank can also help. Submerged pumps are also a source of unwanted heat, and as a solution, reef aquarists favor the ``non-submerged" pumps due to the decreased transfer of heat to the water.

A little recognized source of heat control is through the natural cooling effect of evaporation in wet dry filters, and through the flow of air over the surface of the aquarium. Nevertheless, additional cooling is often required, especially in warm climates.

This is achieved through the use of "freon" style cooler units similar to home refrigerators. They either pass the water through a heat exchange unit, or pass coolant through a heat exchanger in the tank. Those chillers are expensive but not many people have had success in the "do it yourself" construction of chillers. (The "dorm" type of refrigerator is not powerful enough to be of use, just in case you were thinking about this.)

Sterilization

In especially sensitive aquaria, infections resulting from water born parasites, fungi, bacterium and vires can cause serious problems. Water sterilization is most beneficial for breeders (as it can help control infections of incubating eggs), for centralized multi-tank filtration (to control the spread of disease between tanks), and for delicate and/or costly setups such as large tanks and reef systems (as a safety measure). It is important to remember that a healthy aquarium depends on beneficial bacteria typically growing on media in your filter which neutralize ammonia. At most, your sterilizer can kill some water born pathogens, but total sterilization is not possible or desirable. Aquarists who practice prudent quarantine procedures for newly acquired fish generally do not need to sterilize.

Two main types of sterilization are used, ozone injection and ultraviolet irradiation.:

Ozone

Ozone gas is highly reactive and is a powerful oxidizer of organic pollutants, including living pathogens. Another benefit of water treatment with ozone gas is that it systematically reduces dissolved organic compounds in the water stream which increases the reserve capacity of the water to oxidize organic waste throughout the aquarium. Ozone laden water also improves the ability of protein skimmers to generate foam which increases their overall performance. Prior to the discovery of the live rock/protein skimmer "Berlin Method" style of reef keeping, ozone injection was considered part of a "state of the art" filtration system, especially among Europeans in the 1980's. The trend of late is towards the more simple & natural Berlin Method. Though ozone use remains beneficial, it is being used less in recent years among reef keepers.

Ozone gas is produced by devices which create a spark in dry air. As humidity drastically reduces the efficiency of ozone generators most aquarist choose to pretreat the air for the ozonizer with a dehumidifier. Ozone gas is highly corrosive, all elements (especially rubber) which can come in contact with ozone must be made from ozone safe materials (commonly silicone). Residual ozone can be efficiently stripped from air by passing the air through activated carbon. Ozone must not be allowed to enter your aquarium because it can kill your fish and invertebrates and/or damage the beneficial bacterial in your biological filter. Also, ozone gas is unsafe to breath and can cause irritation even in small concentrations.

Ultraviolet Sterilizers

High intensity ultraviolet light destroys the DNA in living cells and can be an effective means to control living pathogens. The most effective UV light is the high energy UV(C) light roughly at the wavelength of 250 Angstroms. To be effective, UV Sterilization (UVS) must expose the pathogens to high enough light intensity for a long enough period of time. Martin Moe cites 35,000 to 100,000 microwatts per second per square centimeter as the norm, which works out to roughly 10 to 25 gallons per hour per watt (or less for units not operating at peak efficiency).

Common problems which can reduce efficiency and kill rate are:

1. Allowing the water to flow too fast past the UV light.
2. Light blockage due to a build up of salt deposits or bacterial slime on the bulb.
3. Fading of the light due to age of the bulb (which typically have a six month life.)

The same property of this light that kills germs can damage your eyes, and special care _MUST BE TAKEN_ to avoid direct or indirect eye contact with this light. [This is especially serious because the damage occurs inside your eyes before you feel any pain. Too many people have already damaged their eyes in this way!] The UV(C) light does not penetrate water very well, so to be effective, UV Sterilizers commonly position the UV bulb close to the water which also can pose a risk of electrical shock should the bulb break, etc..

There are three types of UV Sterilizers:

1. Tray type. (Typically homemade) with UV bulbs suspended in a reflecting fixture over a shallow tray of slow flowing water. Benefits: easily cleaned, can be cheap, can be made large enough for commercial applications. Problems: safety risks to your eyes, too large and awkward for many home uses.
2. Tube type, wet bulb. Tube types have the benefit of exposing all sides of the UV tube to water with no reflector. The water passes directly past the bulb which is mounted in a waterproof tube. Benefits: cheap, compact & effective. Problems: difficult to clean the slime accumulations from the bulb, safety risks due to electrical shock.
3. Tube type, dry bulb. Similar to above, but the UV tube is surrounded by a quartz tube [glass blocks UV(C) light] insulating it from the water. These are more expensive and probably safer. Changing the light bulb is easier and dry bulb tube types can havea internal device to wipe slime from the quartz tube. Some of these types come with sensors to monitor the intensity of the light to let you know when to replace/clean the bulb. etc..

To learn more

See the RESOURCE FAQ for several good books. A good reference work for aquarium filtration is _Marine Aquarium Reference (Systems and Invertebrates)_ by Martin Moe