Aquaponic System Design Parameters:

Solids Filtration, Treatment and Re-use

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Aquaponic systems contain fish and fish release solid wastes. The recirculating aquaculture industry has developed over many years, efficient filtration technologies and approaches to remove solids from the fish culture water. The media-based constructed wetland industry, also over many years, has developed methods and approaches to treat a number of waste water pollutants, including solids, with media-based wetlands.

In aquaponics, we wish to treat these fish waste solids and re-use the nutrients they contain if possible, so that we may gain access to as many of the fish-based nutrients for plant growth as possible. Solids filtration, treatment and re-use may be configured in two main ways:

1. Using standard, established aquaculture filtration methods to quickly remove and separate the solids from the main aquaponic system, treating and mineralising those separated solids away from the main aquaponic system and then returning the mineralised supernatant to the main aquaponic system.

2. Using media beds to perform filtration that keeps the solids within the main aquaponic system and relying on these media beds to mineralise the solids so the resultant nutrients are available in the main system.

In this fact sheet we will look at standard and established recirculating aquaculture methods to remove solid fish wastes and the treatment and re-use of those solids for addition of the resultant nutrients back into the aquaponic system, and standard and established constructed media-based wetland solids removal and mineralisation approaches which act as an ideal model or analogue for aquaponic media beds.

Recirculating Aquaculture Filtration

Traditionally, fish were grown in either static ponds (ie: no or little water exchange occurred) or flow-through raceways or ponds (ie: water is exchanged, often at high rates).

Static pond culture utilises very low fish stocking densities (usually below 5 kg/m^3 of water) and relies on developing a natural ecology in the pond to treat or process the fish wastes (both solids and dissolved wastes). The ecology develops to a point where the waste loads of the fish may be treated and processed by the micro-flora ecology inhabiting the pond. Similar micro-organisms as we see in aquaponic systems inhabit static ponds and process ammonia released by the fish and convert it to nitrates. In addition, other micro-organisms inhabit the pond and process the solid fish waste, break it down and dissolve it into the water column. A myriad of micro-floral life inhabits static ponds and it is this life that biologically processes the system and makes fish production possible.

In flow-through culture (often associated with raceways) the fish may be kept at far higher densities because water is constantly exchanged through the system. Trout raceway culture is the best example of this. In this style of culture, the flow of a river (often gravitational flow) is diverted into the fish holding tanks and the water "flows through" the tanks. Exchange rates of water are very high and so the fish waste is removed quickly and exits the growing tanks quickly. Because water is exchanged, and thus, removes the waste with it, fish may be kept at far higher densities. There is no treatment (mechanical or biological) of the water in flow-through culture and waste processing relies on the physical removal of the waste via the high water exchange rates.

The recirculating aquaculture industry grew out of striving for a way to keep and grow fish in higher numbers in smaller spaces, whilst also trying to use water more efficiently. Water treatment and processing approaches were initially adopted from the sewage treatment industry.

The basic requirements for recirculating aquaculture filtration are:

1. Solids removal.

2. Biological filtration (the conversion of potentially toxic ammonia to non-toxic nitrates).

There are, of course, other filtration processes used now for recirculating systems but the basics are to remove the solid fish waste and biofilter the water.

Recirculating aquaculture systems (or RAS) use far lower exchange rates of water than flow-through culture; an average exchange rate of water in these systems is approximately 10% of the water volume per day. To make the water more amenable to fish keeping, the above basic filtration processes are used and this assists to keep water exchange rates far lower.

RAS Solids Removal

Solids removal is a key aspect to RAS water treatment. Solid fish wastes, if left in the system, start to break down either aerobically (via aerobic bacterial action) or anaerobically (via anaerobic bacterial action) and release dissolved organic materials.

If aerobic conditions are present, the bacteria that break down the fish waste solids compete with the fish for dissolved oxygen and this may lead to a situation where there is not enough dissolved oxygen in the water for proper fish metabolism and health.

If anaerobic conditions are present, the bacteria do not require oxygen and therefore, do not compete for it. However, anaerobic bacterial solids breakdown may cause a number of negative outcomes, such as the release of substances that may be toxic to the fish and other micro-organisms in the system and the raising of system pH.

In either situation, if solids remain in the system they can quickly accumulate to a point where they physically overload the system and can release high organic loads that can affect the fish or cause the system to be biologically and chemically overloaded. If this occurs, the threat of the system crashing biologically and chemically is imminent.

The golden rule for RAS in terms of solids treatment and processing is to remove as many solids as quickly as possible.

Because of this, the RAS industry has developed and evolved a number of mechanical filtration techniques to remove solids quickly from the system. Many of these solids removal approaches have been adopted and evolved from the sewage waste-water treatment industry.

There are several approaches to quickly physically remove solids from water bodies; the two most common are:

1. Sedimentation techniques (the solids are separated from the water column by using gravity to settle them out).

2. Mechanical techniques (the solids are mechanically removed from the water column - eg: screening).

Sedimentation

Sedimentation utilises the force of gravity upon the solid particles to settle them out of the water column. A solid particle has its own mass (or weight) and so gravity will cause it to drop in the water column to the base of a tank. Once at the bottom of the tank an ancillary approach may be used to remove the collected solids from the sedimentation device (eg: active suction removal). The solids that can be removed this way are restricted to the larger particles as the very small ones have a lower mass and density and therefore, do not sink as quickly.

The rate at which a solid particle falls is directly related to the mass of the particle. In addition, if the water flows through the sedimentation tank too quickly then the solids particles do not all have time to fall to the bottom and so stay in suspension and can exit the sedimentation tank with the water flow. Therefore, the key requirements in designing and sizing sedimentation devices are:

1. The flow rate of the water through the sedimentation device.
2. The retention time of the water in the device (which is related to the flow rate and device volume).

The flow rate through the sedimentation device is set by the flow rate of water exiting the fish tanks. As may be seen in my Fish Tank Shape and Design fact sheet, the flow rate of water through the fish tank is dependent on the density of fish being kept in the tank; for low – medium densities (up to 15 kg/m^3) an exchange rate of one half of the fish tank volume per hour is the minimum recommended (generally, 3 quarters of the fish tank volume per hour is better) and for densities above 15 kg/m^3 a minimum exchange rate of 1 fish tank volume per hour is recommended.

The flow rate through the sedimentation device is also dependent on the volume of the device.

Let's look at an example to make this clearer.

If we have 5 x 1,000 L fish tanks, with a fish stocking density in each tank of 30 kg/m^3 and the fish tank exchange rate is 1 tank volume per hour, then the total water flow rate in the system is 5,000 L/hr. If the retention time required to sediment out all the solids we wish to settle using the sedimentation device is 1 hour (so that gravity has enough time to act on the solids particles and drop them to the bottom of the tank), then we need a sedimentation device of 5,000 L water volume. If we decide that the required retention time is 30 minutes, then we need a sedimentation device of 2,500 L water volume.

The longer the retention time, more and smaller solids particles will fall to the bottom of the tank and be separated. Therefore, we should design for as long a retention time as is practically possible in our sedimentation devices. However, we are usually restricted by other factors such as available space, which means we cannot always build large sedimentation devices. The size of the device utilised is therefore, a compromise between the retention time and the available space we have.

If 1 hour, or greater, of retention time is possible, then we should use this. However, if space restrictions are involved, then a minimum retention time is 20 minutes.

The most basic sedimentation device is a rectangular tank; the water enters one end, flows slowly though the tank to allow the solids to settle and exits the other end. The solids are then regularly removed from the base of the sedimentation tank in some way.

In aquaponics, we often see deep flow tanks operating as sedimentation tanks. Because many deep flow channels are long and narrow, and hold high water volumes, they can act as a site for solids sedimentation. This is OK as long as the collected solids at the base of the tanks are removed on a regular basis so they do not accumulate. However, when a deep flow channel is covered with floating rafts, it is often difficult, time consuming and laborious to clean out the solids from the base of the channels. It is far better to sediment solids at a site other than the deep flow channels so it is easier to remove the solids quickly and regularly.

Another form of sedimentation device is the swirl sedimentation tank. This consists of a round tank of the required water volume to meet the retention time required. The water enters the tank in a way that is tangential to the tank wall (meaning that the water enters the tank and is directed along the side wall of the tank). This makes the water in the swirl sedimentation tank "swirl" around in the tank in a circular motion. The solids still settle out of the water column due to gravity, but the swirl action of the water in the round tank concentrates them to the centre of the tank.

Figure 1: A swirl sedimentation tank showing the tangential inlet (bottom of the tank) and the solids being directed to the centre bottom of the tank. The outlet is at the water surface or centre of the picture.

This makes it easy to clean the solids out of the tank as an outlet may be located at the bottom centre of the tank and the solids may be quickly and regularly removed via simple hydraulic pressure (a valve is opened and if the outlet is lower than the water height in the swirl tank, then the solids are simply sucked out of the bottom centre of the swirl tank and removed with the water flow).

Sedimentation tanks also come in other forms, configurations (eg: radial flow separators) and variations, but they all share the same process of using gravity to settle the solid fish waste particles out to concentrate them and assist with fast and regular removal.

There are also a number of other solids separators that use forces other than gravity to separate solid particles, including, but not limited to, vortex separators or cyclone separators.

Mechanical Filtration

Mechanical filtration consists of using some sort of material to screen the water so that the solids are separated from the water; the water will pass through the screen but the solids will not. Screening solids out is dependent on the pore size (or hole size) of the screen material; the smaller the pore, the more solids that may be separated.

There are many different materials that may be used as screens, including mesh screens (similar to the screen material used for "screen printing"), plastic woven screens and filter mats. All perform the same process by restricting the solids from passing through them.

Screen filters come in two basic types:

1. Static screen filters (where the screen does not move and the water passes through it).
2. Moving screen filters (where the screen moves so that its entire surface may be exposed to the water to be filtered).

Static screens are easy to self-build as they basically consist of the screen material being located in some type of housing to support it. Screens should be easily removable so that they may be washed out when required. I often use static screen filters in small commercial aquaponic systems (up to 200 m^2 of plant growing area) as they are cheap to build and easy to operate. However, static screen filters do need active management as screens need to be regularly removed, washed and re-inserted. This active management requirement does restrict the use of this approach; when fish numbers or biomass gets too high, the fish produce so many waste solids that the screens clog regularly and so need a higher frequency of cleaning. In my experience, once the requirement to wash screens rises to above 2 - 3 times per day then they become impractical as the labour requirement (and more importantly, the time needed to be at the system) rises too much.

Figure 2: A static screen filter showing the delivery manifold (to utilise as much of the screen area as possible) and removable filter screens.

The most popular style of screen filter is the drum screen filter. In this approach, the screen is attached to a drum and the unfiltered water enters the inside of the drum and flows through the screen to the outside. Inside the drum there is a switch that senses the water height. When the screen starts to clog with solids, the water doesn't pass through the screen as easily and the water height inside the drum begins to rise. If it rises enough, it trips the switch and the filter enters what is known as the "back flush" mode.

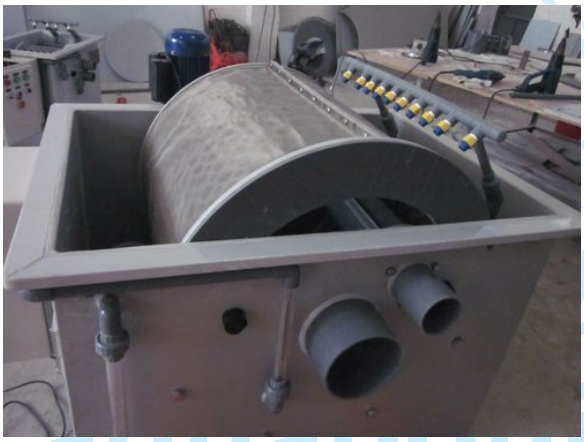

Figure 3: A drum screen filter showing the series of high pressure spray nozzles for the back flushing procedure. (http://china-aquaculture.en.alibaba.com/product/501875208-210823815/Rotary_Drum_Filter_fish_farm_aquaculture_equipment.html).

In this back flush mode a series of high pressure sprays fire on the outside of the drum and wash the collected solids off the screen and into a channel within the drum that is directly opposite the high pressure spray nozzles. This cleans the solids off the screen and collects them in the channel which then directs the solids to an outlet point. Therefore, the drum screen filter is an automatic, self-cleaning filter. This approach makes more sense for larger systems with higher fish biomasses as the automatic cleaning ability means the operator does not need to be present.

Similar to the drum screen filter is the belt screen filter, which operates in the same way except that instead of using a drum, the filter utilises a belt that rotates. These filters are back flushed in a similar way to drum screen filters and are therefore, also self-cleaning.

Mechanical Filtration Using Media Beds

Early RAS experimented with using media beds to separate solids from the water column. Media beds act in a similar way to screen filtration by providing pores (the interstitial spaces between the media particles) for the water to flow through. If the solid fish waste particle is larger than the pore between the media particles, it is blocked and separated from the water column.

What this early experimentation demonstrated was that if the media beds are not sized sufficiently to meet the solids load, they can quickly clog and therefore, the filter looses its effectiveness and often, the water flows out of the top of the media bed and not through it. The second issue identified was that it takes a high labour input to constantly clean out media bed filters. This was overcome to some extent by adopting a back flushing approach where a flow of water was reversed through the media bed to clean the solids out. However, the outcome was that:

1. If the media beds are to be back flushed, the normal water flow through them must be stopped or diverted during the back washing phase, which is difficult to configure.

2. The back flushing process through media beds requires large volumes of water to clean them effectively and this water usually becomes wasted.

Because more effective and more efficient solids filtration processes (ie: screening) were available, RAS stopped using media beds as solids filters a long time ago due to these inherent draw backs.

The Media-Based Constructed Wetland Industry

The media-based constructed wetland industry extensively uses media beds to treat and process a number of different pollutants in water, including solids. Media-based wetlands are used all over the world to treat sewage and other wastes that contain high solids loads.

The media-based treatment wetland approach that is most appropriate to aquaponics is Reciprocating Vertical Flow Wetlands (RVFW).

These wetlands operate in the same way as flood and drain aquaponic media beds do; water containing solids is flooded to a media bed, then allowed to drain. In the flood cycle, the water that contains the waste solids (in aquaponics, fish waste solids) is directed to and enters the media bed. The media in the media bed acts as a solid screen and therefore, separates solids from the water column.

Figure 4: A media-based constructed wetland showing planted and unplanted treatment cells. (http://www.cenews.com/magazine-article----designing_treatment_wetlands_for_the_21st_century-8517.html)

During the drain phase, the water exits the media bed, leaving the solids trapped in the bed. When the water leaves the media bed, the action of it leaving the bed sucks atmospheric air (and the associated oxygen) into the media bed, thus assisting media bed dissolved oxygen concentrations. This oxygen assists the aerobic nitrification process (the conversion of dissolved ammonia to dissolved nitrates) and also assists the aerobic solids mineralisation (solids breakdown) rate.

Media in media beds also attract nitrification (conversion of ammonia to nitrates) bacteria to grow on it. Therefore, the spaces between the media particles are further filled with the bacterial "biofilm" that grows on the media to convert the ammonia to nitrates. This means that if dissolved ammonia concentrations are high (as is the case with fish waste water), then biofilm also inhabits the interstitial spaces and therefore, assists the media to act as an even more efficient solids screen.

The constructed wetland industry has applied much scientific and engineering research to the performance of RVFW's so that they may design and size systems based on the solids loads that enter them.

The point is not that the media bed acts as an efficient solids screening device; it does! The point is that media beds may be too efficient, and because they are difficult to automatically clean or back flush, they may clog with solids very quickly.

Therefore, whilst the media bed acts as a very efficient mechanical screen filter to separate solids from the water column, it must be designed and sized correctly so that it doesn't clog and has the least chance to develop an environment that may lead to deleterious effects.

Solids Treatment or Mineralisation

The whole point of aquaponics is to utilise as much of the fish wastes to provide nutrients for the plants, therefore, we should also try and use the nutrients that we can extract from the fish waste solids. The extraction of nutrients from the solid fish waste is referred to as solids treatment or mineralisation.

Solids mineralisation consists of breaking down the solids to useable plant nutrients. Plants only take up nutrients in their basal form; therefore, treatment needs to proceed as quickly as possible to this basal state.

Solids are treated, mineralised and broken down by bacteria in all aquatic systems, including aquaponic systems. There are two major ways in which bacteria may breakdown and mineralise fish waste solids:

1. Aerobic mineralisation (where sufficient dissolved oxygen concentrations are present so that aerobic bacteria may operate).

2. Anaerobic mineralisation (where zero or ultra-low dissolved oxygen concentrations are present and anaerobic bacteria operate).

Both approaches will produce mineralisation of the fish waste solids to basal, plant available, nutrient forms. However, aerobic mineralisation works faster than anaerobic mineralisation and so should be encouraged (Wallace & Knight, 2006). Therefore, in aquaponic systems we should try and encourage aerobic solids mineralisation as it operates more efficiently than anaerobic solids mineralisation. Thankfully, there are other microbial and chemical processes that occur in aquatic systems that contain fish and plants that also require aerobic conditions and so, aquaponic systems should always operate under these conditions.

Aerobic mineralisation of fish waste solids may be done in a number of ways. In system approaches were modern aquaculture solids separation filtration is used, the solids are removed from the main aquaponic system very quickly. The solids may then be directed to the solids mineralisation device for mineralisation and breakdown and then the mineralised nutrients may easily be added back into the aquaponic system. This approach may be referred to as "off line solids mineralisation", because the solids are mineralised in a device that is not incorporated into the normal water flows of the main aquaponic system.

In systems that utilise media beds for the separation of fish waste solids, the solids are not separated from the main aquaponic system and remain in the system (referred to as an "in line solids mineralisation" approach), therefore, they need to be mineralised in the media bed. If media beds are kept in an aerobic state, then solids mineralisation will proceed as desired at the fastest possible rate and provide the dissolved basal nutrients directly to the plants. The caveat on this approach is that the media bed must be sized correctly so that the solids mineralisation rate may keep up with the rate at which new solid fish wastes enter the media bed. If media beds are sized correctly, and designed to encourage aerobic conditions, then they should operate well as solids filtration and mineralisation devices.

Off Line Aerobic Solids Mineralisation

The easiest, most efficient and cost effective way to aerobically mineralise fish waste solids off line is to use an aerobic bio-digester. This is a fancy name for a well aerated tank where the bacteria may mineralise the fish waste solids!

Basically, the concentrated fish waste solids (as collected from the solids filtration device) are placed in a tank filled with water that is very well aerated. The aerobic mineralisation bacteria that breakdown the solid fish wastes will populate the tank and begin the work of mineralising the fish waste solids and when the process is complete, the dissolved nutrients may be added back to the main aquaponic system.

Aerated mineralisation tanks may be configured in a number of ways; some contain complex baffle systems and screens to separate the water containing the dissolved nutrients from the remaining fish waste solids, some have automatic water and solids addition and automatic nutrient-rich water removal systems etc…However, in its simplest form, a mineralisation tank is a tank containing water and an air stone with aeration applied.

Figure 5: A simple "off line" solids mineralisation tank showing aeration. The pipe and valve at the right is the solids drain from the sedimentation tank to the mineralisation tank.

The operation of the simple version is quite easy and doesn't require much labour time. On a daily basis, the separated fish waste solids are added to the well-aerated tank. Also on a daily basis, water containing dissolved nutrients is removed from the mineralisation tank and added back into the main aquaponic system. It is best to remove clarified water from the mineralisation tank for replacement into the main aquaponic system; if the water is not clarified, you are simply adding untreated solids back into the main aquaponic system!

On a daily basis, the aeration is turned off for an appropriate amount of time to allow the solids to settle (or sediment) to the bottom of the tank. When this is achieved, the clarified water may be easily removed from the mineralisation tank and added back to the main aquaponic system (I sometimes do this by simply using a bucket to decant off the clarified supernatant at the top of the mineralisation tank!). Then, the aeration is turned back on to continue the ongoing solids mineralisation process.

The factor that must be considered in this off line approach is to size the mineralisation tank correctly so that it may easily take the daily influx of solids (and the water associated with those solids). A good rule of thumb is that solids will generally take about 4 weeks to completely mineralise in an aerobic process. Therefore, if the daily influx volume of solids and water is known, then multiplying this volume by 28 days will provide the volume of the mineralisation tank required. I use this simple approach of off line, aerobic solids mineralisation for small commercial aquaponic systems and always build in a 20% over-sizing factor so that I am sure I will meet the mineralisation tank volume requirement.

Media Bed or In Line Aerobic Solids Mineralisation

On the surface, using a media bed to mineralise fish waste solids appears to be a simpler approach, as the solids remain in the bed and are processed there. However, it must be remembered that if solids are allowed to stay in the main aquaponic system, then there is no control over the effects they may have on the biology and chemistry of the system. This is important because solids mineralisation requires several steps. The first step is the break down of the solids to organic macromolecules (large molecules of an organic nature), which consumes system-based dissolved oxygen. Many of these organics dissolve directly into the water and therefore, may be released from the media bed.

Plants will not take up these large organic molecules and they need further mineralisation processing to be plant available. If they are released from the media bed then they must be further mineralised before the plants can use them and this further mineralisation process also consumes system-based dissolved oxygen. It also means these organics can roam around the main aquaponic system and that further mineralisation may occur in areas where we do not want it to compete for dissolved oxygen (eg: the fish tanks or deep flow beds).

Therefore, by leaving the fish waste solids in the main aquaponic system, we are allowing them to compete for the available dissolved oxygen in any part of the entire aquaponic system and we have no control over the amount of dissolved organics there are in the main aquaponic system.

In addition, when solids accumulate in media beds they have a high potential of causing anaerobic zones, which can have negative biological and chemical effects on aquaponic systems.

As has been discussed, media beds will operate as efficient solids mineralisation devices, however, this only occurs if the beds are designed and sized correctly (for a further discussion on sizing media beds for solids mineralisation, see my Media Beds and Sizing fact sheet).

As we have also seen, the constructed wetland industry has spent many years performing research to enable the correct sizing and design of media beds for solids treatment and mineralisation.

Therefore, this knowledge may be used and directly applied to aquaponic media beds so we may have tools to accurately predict the size of the media bed(s) required to efficiently treat and mineralise the solid fish waste loads entering them on a daily basis so we can lower the chance of the solids causing any ill effects (see my Media Beds and Sizing fact sheet for a further discussion on sizing media beds).

Conclusion

We have seen that efficient and fast solids separation is paramount to optimised fish keeping and health. We have also seen that fish waste solids may be separated using a number of modern aquaculture methods (ie: sedimentation and screening). In addition, screening may be achieved via approaches that allow us to remove the solids from the main aquaponic system very quickly or via approaches that leave the solids in the main aquaponic system (ie: media bed screening).

No matter what separation method is utilised, we have also seen that solid fish wastes contain nutrients and if they can be treated and mineralised, they may be available to the system for eventual plant up take and use.

Off line solids mineralisation allows us to treat and mineralise these solid fish wastes outside of the main aquaponic system when they have been separated via modern aquaculture approaches, which confers advantages in terms of not relying on the main aquaponic system itself to perform the mineralisation and avoids any associated risks of leaving the solids in the main aquaponic system (ie: dissolved oxygen consumption and competition and high organic loads).

In line solids mineralisation may be utilised via the use of media beds, but as we have seen, this relies on carefully and accurately sizing and designing the media beds so they encourage aerobic conditions and so they can handle the solids load that is placed in them, with the end point being that the solids mineralisation rate is equal to, or greater than, the rate at which the solids enter the system, so that clogging of the media and anaerobic zones may be avoided.

It is, of course, up to the aquaponic designer, teacher and operator to decide which method is most appropriate for their particular aquaponics application.

A Final Word

I want to make it clear that I am not opposed to the use of media beds as solids separation, treatment and mineralisation devices in aquaponic systems; I have, and still do, design, construct and use media bed aquaponics systems myself.

What is important is that aquaponics designers, teachers and operators ensure that they are well versed in the complexities of how media beds perform and operate and are sizing media beds correctly so that there is a level of predictability in terms of the media beds solids treatment and mineralisation capacity and performance.

The requirement for complete and optimised solids mineralisation in hobby-scale aquaponic systems is usually met because most hobbyists utilise low fish culturing densities and biomasses. However, many examples persist where the amount of solid fish wastes entering the media bed is greater than the media bed can handle in terms of solids mineralisation and solids begin to accumulate.

The accumulation of fish waste solids (or worm castings) leads to anaerobic conditions which can have negative outcomes and the over-accumulation of solids in hobby-scale media beds is the main reason why many people experience pH rises or constantly high pH readings without using any regular buffering procedure.

In a hybrid commercial aquaponic system context, designers, teachers and operators should make themselves aware of the limitations of media beds in terms of their capacity to treat and fully mineralise solid fish wastes and avoid clogging (and the associated, harmful anaerobic conditions) over long-term time scales.

Adopting the available science and engineering for media bed treatment rates for solids (from the long-established constructed wetland industry) is an immediately available way to at least try and provide some predictability to the sizing of media beds, or the proportion of media beds required in hybrid style aquaponic systems so that adequate solids treatment and mineralisation is occurring when and if media beds are being used as solids separation and mineralisation devices. This allows a higher degree of certainty and confidence when designing this style of aquaponic system.

Happy Aquaponicing

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Wallace & Knight (2006). "Small-scale constructed wetland treatment systems: feasibility, design criteria and O&M requirements." WERF. IWA Publishing, London, UK.