Aquaponic System Design Parameters:

Fish Tank Shape and Design

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As we all know, aquaponic systems (hobby-scale or commercial) contain several key components; the fish component, the plant component and a filtration component. A major component of the entire aquaponic system is the fish component.

The fish component is the space in which we hold the fish in the overall aquaponic system. This may be in a single tank configuration (as is often used in hobby-scale aquaponic systems) or a multi-tank configuration (as is often used in commercial scale aquaponic systems). There are many shapes and ways to hold and grow fish, so in this fact sheet we will take a look at the choices available in terms of the established principles of aquaculture and how they relate to fish tank shape and design.

Tank Design, Fish Health and Well Being

Fish health is critical to optimised aquaponic performance. Fish, like any other animal, deserve our best efforts to make sure they are living in a way that is conducive to their health and well being. In this sense, fish tank design can be critical.

Water quality control is paramount to fish health and well being. Much scientific research has been performed to try and elucidate the best fish tank design for fish to live happily in and to optimise water quality control. When it comes to fish tanks, the general accepted outcome is that water movement through the fish tank is optimised to provide the best water quality possible. This, therefore, directly relates to the fluid dynamics and the shape of the fish tank.

Optimised water movement through fish tanks relates to several key parameters:

1. The flow rate through the fish tank (eg: Litres/hour).
2. The water turnover rate (eg: fish tank volumes exchanged per hour)
3. The optimisation of the fluid dynamics of flow that ensures ALL water enters and leaves the tank in the required way.
4. The tank is made from acceptable materials that ensure the lowest exposure of the fish to potential toxicity.

Materials for Construction

The two safest (and often cheapest) materials to make fish tanks from are Fibreglass and Polyethylene (PE). Both, once adequately cured and hardened, exhibit few, if any, abilities to form toxic compounds that may affect the fish and are often graded as "food safe". For these reasons, the vast majority of available for purchase fish tanks are made from these two materials.

Other materials are possible, including stainless steel or PE as a liner. For convenience and affordability however, it is difficult to find alternatives to fibreglass and PE pre-formed or pre-moulded tanks.

Fish Stocking Density

Fish stocking density is the weight of fish held related to the holding volume of water. The accepted approach for stating fish stocking density is the kilograms (weight) of fish per litres (volume) of water. As a standard, this is most often stated as kg/m^3 (1 m^3 of water = 1,000L).

Large, commercial recirculating fish growing facilities keep fish at densities up to approximately 50 kg/m^3 in aerated systems and up to 150 kg/m^3, or higher, in direct oxygen injected systems. Aquaponic hobbyists rarely approach these high fish densities in their hobby-scale systems; however, this does not mean that the standards of fish tank design should not be adhered to, to ensure fish health and well being via water quality optimisation (most hobby aquaponics practitioners keep fish at densities well below 20 kg/m^3). Commercial aquaponic operators will often reach high, aerated fish stocking densities as this is required for acceptable capital costs, and so, standards of fish tank design are often critical.

Flow Dynamics in Fish Tanks

It has been proven scientifically that round fish tanks provide the best fluid dynamics. This is due to the fact that round tanks exhibit no "corners" in the vertical dimension and so water is free to flow into and out of the tank uninhibited. Corners in fish tanks have the ability to slow or fasten water flows in particular tank regions. They also have the ability to cause areas of low to no water exchange, meaning that the water in these areas may be retained in the fish tank for extended periods of time that do not reflect the required flow for all the water in the tank to ensure correct water quality control.

The main reasons to ensure correct flows through fish tanks are:

1. To ensure timely fish waste solids removal.
2. To ensure timely and adequate biofiltration of the dissolved fish wastes (ie: conversion to non-toxic nitrate from potentially toxic ammonia).
3. To ensure adequate dissolved oxygen levels are maintained in the entire water volume.

If water within fish tanks does not have the chance to adequately mix and adequately flow through the tank (as sometimes occurs in non-round fish tanks), then some of the total water body may harbour areas of high solids load, high dissolved ammonia load and low dissolved oxygen levels.

In addition, these "dead zones" of lowered water exchange and movement can also cause zones of non-optimised water chemistry. This may be exhibited as areas of high or low pH, conductivity (EC), dissolved oxygen (DO) or water temperature.

At the low fish stocking densities often used in hobby-scale aquaponic systems, these factors are usually not too much of an issue as water quality may be maintained adequately based on the fact of the low fish stocking rate. However, this does not mean that hobby-scale aquaponic practitioners should completely ignore the facts related to fish tank shape and design. In commercial aquaponic systems, fish holding needs to be optimised and so higher densities are often employed and therefore, water quality optimisation and maintenance is paramount to overall system efficiency and these factors become far more critical.

Water Flow Rate and Fish Stocking Density

The rule of thumb for water flow rate through a fish tank is to make it as fast as is practically achievable. Practical achievability is based on many factors, including, but not limited to:

1. Water velocity – if the water velocity is too fast then the fish must constantly swim against the flow and sometimes this may negatively affect fish health. If it is too slow, then the fish may not swim enough and suffer alternative negative affects to their health.
2. Water turnover rate – the water volume of the fish tank must be exchanged at a rate that is adequate to meet the water quality requirements of the fish.
3. Fish waste solids concentration – the water should flow at a rate that allows the solid fish wastes to be concentrated in a region of the tank that allows their removal at a rate that is adequate to

meet the water quality requirements of the fish.

4. Fish dissolved waste concentration – the water should be exchanged often enough to ensure that the dissolved ammonia produced by the fish does not reach concentrations that may negatively affect fish health.
5. Water entry to the tank – the water should be directed into the tank to ensure adequate mixing and to ensure the required water velocity is achieved but not exceeded.
6. Power consumption – the power required to achieve the flow rate must be as efficient and economical as possible.

As already stated, hobby-scale aquaponic systems usually use low fish stocking densities, so adhering to the above requirements does have an amount of flexibility to it. Commercial systems are somewhat different and more exacting and the above requirements are critical to optimised production. In general, the most important factor is the requirement to meet adequate water turnover rates in the fish tank.

The turnover rate of water through the fish tank is a function of the fish stocking density; the higher the density the more turnover required. The turnover rate of water through the fish tank should be at least one half of the fish tank water volume every hour where the fish stocking density is less than 15 kg/m^3. For situations higher than this fish stocking density, a water turnover rate as close to one fish tank water volume per hour should be aspired to. In commercial situations, 1 fish tank volume of turnover per hour should be the minimal design criteria, but remember, don't go too high as the water velocity achieved may become too high for the fish species being cultured. These water turnover rates will ensure that dissolved fish wastes (ie: ammonia) don't build to toxic concentrations and dissolved oxygen concentrations will be adequate.

For round fish tanks, a tangential flow of water entering the tank (ie: parallel to the wall of the tank) will ensure adequate mixing of the tank water so as high a percentage as possible of all of the water in the tank is exchanged at the required rate. For non-round fish tanks, the operator should choose the best water entry to the tank approach possible; determining this is often very difficult due to the complex nature of water flows in non-circular tanks.

Water Flow and Solids Concentration

If water entry to the tank, when using round fish tanks, is directed tangentially then this causes the entire tank water volume to begin to swirl in the tank. This swirl causes the settleable solids (those solids that sediment to the bottom of the tank quickly) to move towards the centre of the tank due to the centripetal forces involved. This provides advantages in terms of solids removal in two cases:

1. Where a bottom, centre outlet is used in the fish tank – the solids migrate quickly to the centre of the tank and therefore, exit the centre outlet quickly (usually commercial situations).
2. Where an internal, submerged water pump is used – by placing the submerged pump at the centre of the tank, the solids are quickly pumped from the fish tank and removed quickly.

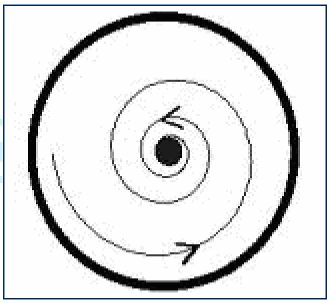

Figure 1: Diagram of solids moving to the centre of a round fish tank with tangential inlet water flows.

It is far more difficult to state where the outlet or submerged water pump should be placed in non-circular fish tanks because where the solids will actually settle is far more difficult to determine. And this is the single most important factor in choosing round or circular fish tanks; they allow predictability of water flows and solids removal.

Fish Tank Surface Area to Volume Ratio

The surface area to water volume ratio of any fish tank (of any shape) is also important to correct fish tank operation. Fish tank surface area to volume ratio is important in terms of the gas exchange abilities of the tank water body. This is because the majority of the gas exchange of the water body in the tank occurs at the water surface (eg: oxygen uptake, carbon dioxide release). If the surface area is too low compared to the water volume (eg: deep, narrow tanks), then the potential gas exchange rate may be restricted to the point where not enough oxygen can enter the water body and not enough carbon dioxide can be released from the water body. Therefore, fish tank surface area to volume ratios should be as high as is practically possible, with a minimum ratio of 1.0.

As an example, an "off the shelf" round fish tank of $2m^3$ (2,000L) water volume may have a 2m diameter, a 1m radius and a 1m depth, meaning the approximate surface area is $3.14m^2$. This means the surface area to volume ratio is greater than 1 (3.14/2 = 1.57).

Conclusions

Fish tank component design for aquaponic systems has much precedent and research to draw upon from the established recirculating aquaculture industry. Fish tank shape and design is dependent on many factors related to water flows and mixing, gas exchange, fish density, water quality requirements, fish waste solids removal and dissolved fish waste treatment, and aquacultural science and engineering has established conclusively that round shaped fish tanks are the optimised shape.

Hobby-scale aquaponic practitioners usually keep their fish at relatively low stocking densities and so a proportion of the requirements and performance attributed to round fish tanks within main stream aquaculture may be flexible in hobby-scale aquaponics situations.

However, providing the best environment for your fish should be a key requirement in any aquaponic system and so utilising the established principals of fish tank design and shape from the established aquaculture industry makes sense and if possible, should be adhered to.

Commercial aquaponic practitioners usually keep fish at densities which approach the established recirculating aquaculture industry and so the requirements and performance of correctly sized and shaped fish tanks is important to optimised system operation and water quality. Providing the best environment for your fish should be a key requirement in any commercial aquaponic system and so utilising the established principals of fish tank design and shape from the established aquaculture industry makes sense and should be adhered to.