Commercial Aquaponic Systems –

The science and engineering of integrating recirculating fish culture with hydroponic plant production.

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Acknowledgements:

Preface:

Aquaponics is becoming one the fastest growing areas in the agricultural technology production space. Even though aquaponics is becoming very popular, little, if any, scientific or engineering knowledge appears to be currently applied to it. Despite this anomaly, many small and larger aquaponics enterprises are being constructed and applied in the urban and vertical farming sectors and unfortunately, many are failing. Many of these failures are due more to the exacting economic conditions required to make small, urban farming enterprises viable businesses. However, system technical design and management issues also represent a good proportion of the reasons behind failure.

Aquaponics, in a commercial context, is essentially the integration of two established technical production approaches; Recirculating Aquaculture Systems (RAS) for fish production and hydroponics for plant production. It therefore makes sense to try and use the existing hardware (components), knowledge and expertise associated with these two technologies to design and configure commercial aquaponic systems, rather than taking an approach to start over again from scratch. Again, and often sadly, this freely and broadly available existing knowledge is rarely utilised in many current aquaponic designs.

Another important aspect of aquaponics is the development and evolution of the varying methods used to integrate fish production with plant production. Classically, the term aquaponics is applied to fully recirculating system designs where the water used is completely shared between the two major components (fish culture and plant culture). However, in the last few years, the sharing of the nutrient resources available in aquaponic systems between the fish and the plants has undergone a development towards other technical integration approaches and so now, the definition of what is "aquaponic" has broadened to also include designs which are either non-recirculating (eg: using the waste nutrient streams produced by standard RAS to feed a plant culturing unit with no return of water to the fish component) or semi-recirculating (eg: using the available nutrient-rich waters on a side stream loop).

The purpose of this book therefore, is to not repeat the knowledge that is already available for standard, tank-based fish production (RAS) or standard hydroponic plant culture in detail, but to rather concentrate on the requirements of the integration process so as to produce the most efficient and optimised aquaponics designs and management methods available. This book will therefore not go into detailed design or engineering aspects of either the fish or plant culturing components of the aquaponic system design process; all of which may be found in other, excellent references and resources related to stand-alone RAS fish culture and stand-alone hydroponic plant culture. Rather, it will concentrate on the application of science and engineering principals to the integration of these two existing technologies in a number of ways that meet the ultimate aquaponic outcome; the efficient and optimised use of the nutrient resources (ie: fish feed) added to the system.

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aquaponic solutions

Chapter 1: Introduction

What is Aquaponics?

In its simplest form, aquaponics is the use of fish waste nutrient resources to hydropincally culture plants. Classically, the term aquaponics was applied to system designs that recirculated the water in the system between the fish and plant components to thus, share (and attempt to balance) the available nutrient resources produced by the fish as a waste product with the nutrient requirements of the plants. Aquaponic designs however, have moved beyond the fully recirculating context. This evolution in aquaponic system configuration has occurred because more researchers and designers wish to fit the aquaponic integration process with existing fish or plant production technologies and enterprises (eg: adding a plant culturing component to an existing RAS, or adding a fish culturing component to an existing hydroponic facility). Classical, fully recirculating aquaponic design approaches, whilst still applicable, are not always practical in this context.

An excellent example of this effect of impracticality is sizing a plant culturing component that will fully integrate and balance in a fully recirculating context with an existing RAS facility of hundreds of tonnes of fish production per year. In this case, the plant growing area required to fully balance hundreds of tonnes of fish production per year is very large and therefore, very expensive. In addition, it also requires the RAS operator to change the management approach they have grown to utilise. This is often a "bridge too far" for the RAS operator, who does not wish to risk changing the management practices they have taken years to learn and perfect. What is generally preferable to the existing RAS operator is to be able to simply treat and utilise the waste stream of water and nutrients which arise from the RAS facility, rather than changing the entire RAS set-up. In addition, this approach of treating RAS waste streams with hydroponic (or other), plant culturing components, allows the business enterprise to choose or tailor which product they will concentrate on (the plants or the fish) as the profit generator.

The above discussion outlines the fact that aquaponics has now moved beyond its fully recirculating pedigree and therefore, it is time to also evolve the definition of what aquaponics actually is or means. Because there are many different technical design approaches and aquatic resource (water and nutrients) sharing proportioning approaches now available, and because some of these are not fully recirculating, it seems pertinent to re-define the term aquaponics beyond a fully recirculating context. In addition, as stated earlier, aquaponics is essentially based on nutrient resource sharing between a fish component (RAS) and a hydroponic component and therefore, a definition based on the nutrient resource sharing capabilities of the technology is probably more appropriate. Rather than simply saying aquaponics is the combination of aquaculture and hydroponics, it is more pertinent to say that aquaponics is an aquatic nutrient resource sharing technology that combines tank-based fish culture and hydroponic plant culture technologies. In this sense therefore, it seems more appropriate to concentrate an aquaponics definition on its nutrient resource sharing capabilities, rather than the integration of two technologies or the hardware involved.

A new proposed definition of Aquaponics therefore, may well be one that concentrates on the minimal nutrient sharing capability the system design offers. In this sense, one of the largest defining factors of aquaponics is that the majority of the plant nutrients provided arise from the wastes produced from fish production. However, when taken in this context, the question arises; what are the possible upper limits to the proportion of nutrients fish waste can supply for balanced and healthy plant production? I would contend that the best and most efficient aquaponic system designs and models currently available provide the vast majority of the nutrients required for plant production from the fish. However, the facts of the science of the nutrient dynamics involved fully support the case that fish waste, as produced by fish fed current pelletised, nutrient balanced fish feeds, cannot provide all the nutrients required for healthy plant production. Therefore, any definition based on nutrient resource sharing in an aquaponic context must take this fact into account.

In the above context therefore, my personal definition of aquaponics is:

"A system of integrating tank-based fish culture and hydroponic plant culture whereby 80% or more of the nutrients required to grow the plants arise from the fish waste."

Of course, the definition of aquaponics will always be something of a contentious issue and not everyone will either agree with me or each other. For example, I have met many people across the globe who believe aquaponics should include the culturing of fish in the water of normal and standard hydroponic plant production technologies and methodologies (meaning that all or the majority of the nutrients used for plant growth are inorganic hydroponic salts and few fish are swimming around in the system). Because my definition of aquaponics is based on the efficient and optimised utilisation of the nutrients that arise from fish waste for plant culture, these style of systems do not fit my definition. As stated, some people may not agree, which is of course, their prerogative. The definition I have provided is somewhat broader than the one I would have applied some years ago, where I restricted my definition of aquaponics to fully recirculating technology integration rather than basing any definition on the nutrient resource sharing capabilities. And I believe this is OK because if you look at the definitions of many technologies, it is far more appropriate to accept that any definition should evolve and develop with the technology itself, rather than trying to restrict it.

Is Aquaponics Natural?

A big advantage that is often stated with respect to aquaponics is that it is "natural" or "organic". That may well be true, however, what defines the term natural? In an aquaponic context, when the term natural is applied, it seems to be associated with the fact that plants are growing using nutrients arising from fish wastes (another reason to evolve the definition way from technology and more towards nutrient resource utilisation?). This is a similar argument as related to what defines naturally grown, soil-based food (such as in organic or biodynamic soil-based production systems); plants grown using animal derived fertilisers rather than chemical or "man-made" fertilisers. In addition, this also generally includes a reference to the fact that microbes play a pivotal role in converting or making those animal derived nutrients available to the plant in a form that is easy for the plant to utilise. These arguments in an aquaponic context, as they do in a soil-based farming context, seem to make good sense. So, if it is these aspects that define aquaponics as natural, then that is fine.

However, unlike soil-based natural farming systems, aquaponics as a technology relies on many un-natural components. For example, fish are kept in plastic, fibreglass, concrete and other materials; hydroponic components are made from plastic (NFT, deep flow and media bed liners), concrete, metal or other un-natural materials and even pumps are made from these material as well, and so on. The use of these materials and the inputs of other things with arguably un-natural origins (eg: electricity) could render aquaponics as being un-natural in other contexts than those that render it as being defined as natural.

Therefore, it could be concluded that aquaponics in its totality is either natural or un-natural. I believe it is more appropriate to be more exacting if the terms natural or organic are going to be applied to an aquaponic context. Therefore, for me, it is acceptable to say that aquaponics relies on natural biological processes of nutrient generation (fish waste), conversion (bacterial mediated) and utilisation. But, it is not acceptable to apply the terms natural or organic to the overall technology as a whole.

Is Aquaponics Sustainable?

The same arguments for deciding if aquaponics is natural may be applied to whether aquaponics may be considered sustainable. In terms of the nutrient and water resource sharing abilities and efficiencies of the aquaponic approach, it is most likely acceptable to say that aquaponics is sustainable, because it tries to utilise as much of the nutrient that is added to produce useable outputs (fish and plants), it tries to utilise the water involved as efficiently as possible and it tries to negate the requirement to release nutrient-rich waste streams back into the surrounding environment. However, again and as for the natural label discussed above, applying the term sustainable to a technology that uses many materials with high values of embodied energy (plastics, concretes, metals, etc.), relies on fish feeds produced from naturally sourced fish meals and oils (in the current, commercial context) and uses electricity for pumping and aeration requirements, it does seem a stretch to apply to term sustainable to the whole of the technology.

How Aquaponics Works

How aquaponics works is simple to understand when you know all of the processes involved. Because there are so many processes involved, it can sometimes seem complex and detailed. However, the basis of aquaponics and how it works is quite simple and can be easily understood when you know it follows fairly basic and wide spread processes found in nature. The natural world itself, that which is all around us, works because all the life on the face of the planet has evolved with one overriding factor applied to it; the efficient (ie: not wasteful) sharing and utilisation of nutrient resources. In its basic form, life is represented by animals that eat things and produce wastes, plants that eat things and produce wastes and microbes that, you guessed it, eat things and produce wastes. The grandeur of life on this planet is that it tries to share these resources by producing and evolving animals, plants and microbes that fit into very specific niches so as to allow the individual to exploit the resources that are available to it.

For example, a lion will eat a gazelle, utilise the nutrients from the gazelle it needs to grow and repair its own cells and to produce energy for itself, and then release whatever else it cannot use by way of liquid, gaseous and solid waste products that it releases into its surrounding environment. Some of that waste will be utilised by microbes for their own growth and metabolic requirements and some of it will be converted by those microbes as part of their own metabolic pathways. Some of the waste the lion produces will also be directly used by plants as a nutrient source and some of it will only be used by plants as a nutrient source after it has been adequately converted by the microbes. This short, very simple and very incomplete breakdown of life on the African plains is used to illustrate how nutrients flow through environments and life in a holistic sense.

An aquaponic system is designed to operate in essentially the same way. The fish, plants and microbes present utilise and share the available nutrient resource between each other in ways that the natural world has honed and evolved over millions of years. In nature, many of the present animals, plants and microbes are completely and inextricably reliant on each other so that the individual gets its requirement and share of the available resources. Aquaponic systems simply rely on these existing associations, partnerships, etc. between the animals (fish), plants and microbes present, that have evolved over millions of years to be highly efficient, to grow the products we require (ie: food in the form of fish and plants). In reality, the life form often not thought about in an aquaponic context, but which has a pivotal and large influence in terms of the sharing and utilisation of the available nutrient resources, is us (humans), because we provide the nutrient inputs to the system (ie: the fish feed) and also share in the nutrients available by harvesting out the fish and plants we require to eat to gain access to the nutrient resources we require.

Aquaponics works to grow fish and plants because we add in the essential nutrient inputs (the fish feed), we provide some of the energy required to enable this nutrient resource sharing (ie: electricity) and the sun and air around us supplies the energy and some of the input nutrients or elements also required (carbon and oxygen). Basically, we try to integrally link into existing nutrient resource sharing processes that occur in the natural world, via technology use and application, so we can control the production and proportion of the products we need for ourselves.

Therefore, in its simplest form, how aquaponics works is via the human engineered sharing of nutrient resources between a suite of living organisms that work in concert together to efficiently share those available nutrient resources amongst themselves.

The Ethics of Aquaponics

As we have seen, and many of us already know, aquaponics is the human engineered sharing of nutrient resources among a suite of living organisms. Human engineered simply means we have designed and constructed the system to enable us to provide the best conditions for all the organisms involved so as to provide the most productive and efficient pathway possible. In this sense, to enable us to contain the organisms involved, we must design and engineer the vessels (environment) or conditions (again, environment) they live and exist within.

The important point is that the primary driver is for the aquaponic system to be as efficient and productive as possible. However, the ethical point is that we do this in a way that is responsible and aware of the life that is under our care and to some extent, control. I have seen many aquaponic systems, especially in a hobby or backyard context, but also in a commercial context, where the humans that own them are happy but the fish, microbes and plants are not. My number one example for this is the operating pH environment I often see fish subjected to in aquaponic systems. I see many systems which are never buffered to control the pH and the fish are living in water with a pH that is acidic (ie: below pH 7). I would have thought that most people would understand what the term acidic means or at least be aware that acids are often sited as being dangerous to us humans as they can at the least, cause burns to our skin or other organic areas. I therefore have no understanding how anyone can justify keeping fish in acidic water conditions. Fish have evolved to and spend their entire lives in a water environment and therefore, the chemical state of that water has a large effect on them. Most fish have an internal pH that is closely matched to their surrounding environment and therefore, if they are freshwater species, like those we keep in aquaponics, then their internal pH is close to about a pH of 7.2. When a fish is then placed into an environment of lesser pH, it can be very stressful to the fish at the worst and at the least, it can cause the fish to use valuable energy to work against that external pH and try and keep its internal pH at balance. In addition, as I said earlier, and as many people know, aquaponic systems naturally tend towards acidic water development if not buffered correctly and so the fish are externally subjected to conditions that we as humans recognise ourselves would be harmful to us.

The ethical question is therefore, if it is not acceptable for us humans to live in less than perfect conditions then why should it be acceptable for fish or any other organisms present with our aquaponic systems?

The answer is simple to me if you have a practical, grounded and ethical view point; it is not acceptable!

Therefore, it is our ethical responsibility to ensure that if we are going to employ an aquatic food production technology, like aquaponics, that we have control over, it is incumbent upon us to make sure we provide the best conditions we possibly can for all the life that lives and exists in that system.