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Corallimorphs! The intricate surface pattern of a *Discosoma sp.* mushroom coral rivals the most surreal imaginations of alien worlds.

Photograph by Leonard Ho

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FEATURE ARTICLE

Water Flow is More Important for Corals Than Light, Part V

By Jake Adams

Just as aquarium lighting has received a thorough reevaluation, so too must we start to consider how the water movement of our aquariums translates into water motion which is relevant and suitable for coral health.

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Introduction

In recent years there has been a great amount of varied and original data produced on lighting and corals for the reef aquarium. By contrast, there have been much fewer articles on the effects and importance of water flow in the reef aquarium. Most aquarists are unaware of the relationship between laminar and turbulent flow and virtually no one ever discusses water motion for reef aquarium in terms which actually apply to fluid dynamics. It's time for the reef aquarium hobby to catch up in the flow department. Just as aquarium lighting has received a thorough reevaluation, so too must we start to consider how the water movement of our aquariums translates into water motion which is relevant and suitable for coral health.

Describing the ideal flow

For lack of a better value, aquarists describe the amount of water motion in their reef aquariums in terms of turnover rate. If identical powerheads are placed at opposite ends of an aquarium but one powerhead is facing the center of the aquarium and the other powerhead is facing the aquarium glass, the powerhead which is directed towards the center of the aquarium will undoubtedly produce faster flow speeds and more circulation throughout the aquarium. Although the powerheads both have the same turnover rate their orientation to the main water mass has a great effect on the flow speeds they will produce. Since flow speed is the critical measure for determining the rate of gas exchange, turnover does little to convey how fast a coral will respire and photosynthesize.

In the natural environment, the reef surface and the corals which live on it experience mostly random, chaotic flow in the form of oscillatory surge. In most cases, aquarists interpret "random, chaotic flow" to exclude laminar or unidirectional flow. This interpretation usually translates into a bevy of powerheads and inlets arranged to resemble what I call a squirt gun firing squad. Although reef aquariums are an attempt at recreating a natural environment, trying to reproduce surge with the scale and energy of the natural environment would take tremendous effort and resources. Whereas the oscillatory surge of the natural environment entails movement of the entire water mass, the typical aquarium features small plumes of water movement which lose velocity and momentum with distance away from the source of water flow (Harker 1998). Water flow which is exiting a powerhead or other outlet begins as high speed, unidirectional flow. However, as the flow increases distance from its source, resistance from other flows and viscous friction cause the orderly flow to quickly lose momentum. At this point the flow loses velocity and it increasingly becomes multidirectional, turbulent flow. Riddle illustrated this phenomenon using a digital electronic flow meter (Riddle 1996). The flow emanating directly from a Hagen 802 powerhead displayed velocities upwards of 70cm/s whereas the measured velocity was 0 cm/s only 60 cm away. This does not mean that there was no flow at that distance but rather it means that either the flow was not properly aligned with the flow meter or the sum of the multidirectional flows had a net velocity of 0cm/s. It is true that turbulence leads to an increased rate of mixing, but fast laminar flow will become turbulent as soon as it encounters an irregular surface such as that of a coral. The faster the flow speed, the greater the amount of turbulence produced when the flow encounters a surface. Although turbulence is the desired end product of water movement, aquarists should be more focused on producing faster unidirectional flow.

The Flow Environment

The environment in which fluid movement occurs has a great effect on how the fluid will behave. The three things that will impact water movement in an aquarium are the dimensions of the aquarium, the relief of the live rock reef structure including the corals, and the force and duration of the water motion.

When considering an aquarium for use as a reef tank, it is important to remember that the dimensions of the reef tank will have a great influence on what kind of reef it will be. The size and shape of the tank will determine the type of lighting to be used, how maintenance will be performed, the type of fish and corals it can hold and how water flow will behave within the glass. As a stickler for water motion I usually consider the last criteria first. In a small aquarium, the water will be easy to flow throughout the entire aquarium, mass water movement will occur very quickly but there will not be much heterogeneity of flow speeds. In a smaller aquarium, viscous forces cause most of the water movement to move at a similar speed and it could be hard to provide suitably slow and fast water flow speeds for the corals which prefer one or the other. In a larger aquarium, it will take more force to move the entire water mass and it will take longer for the entire volume to circulate. However, once the entire water mass of a larger aquarium is moving, it will have more inertia and it will be less impeded by the reef structure or corals which project into mainstream flow. It is easier to produce a variety of flow regimes in larger tanks. Since a larger tank will be governed more by kinetic than viscous forces it is more likely to feature a narrow band of faster flow at the surface and a broader band of slower flow at the bottom.

As you might expect, the more live rock you have in an aquarium, the harder it will be to provide adequate water movement to the volume of the entire tank. Since I prefer to view corals from above, I generally use as little rock as possible. We have all heard the suggestion that a reef aquarium requires 1-2 pounds of live rock per gallon but since the density of live rock varies greatly, this is not a very useful guideline. As you can see in figure 1, my personal preference is to build a reef structure which occupies no more than about 25% of the actual volume of the aquarium. This restriction equates to a live rock arrangement which can be most of the length of the aquarium but it shouldn't be much more than half as high and half a wide as the dimensions of the aquarium. Although new aquarists might be inclined to call this kind of set-up "empty," a patient aquarist knows that this modest amount of rock leaves plenty of room for corals and growth.

In the ocean, surface currents of water are driven mostly by wind blowing across the surface of the sea. The amount of water moving in those currents is proportional to the force of the wind and the duration for which it blows, which is called the fetch. Since aquarists do not use wind to move water, for our aquariums we can think of the fetch as the duration that a mass of water is pushed in a particular direction. Commercially available "wavemakers" are not designed or constructed on anything more than the status quo of the coral hobby which is that corals and reef aquariums need "random, turbulent flow." Apart from their high price, my biggest complaint about these pump controlling devices is that their outlets are switched on and off with such short intervals that they do not allow for an optimized fetch of water flow. By turning off a pump before it has had a chance to reach its full water movement potential, a water pump in this scenario essentially sends out a plume of water movement which encounters a lot of resistance from the inertia of the water volume. By increasing the duration that a water pump is turned on, the moving parcel of water will gain size and momentum so that when the pump is turned off, the water volume should continue to move through the aquarium for a short time. The capacity for wavemakers to produce mass water movement can be ameliorated by increasing the timing interval between pumps and designing pump circuits which work together to move the entire volume of the aquarium.

The final consideration for the flow environment is the placement of invertebrates in regions of the aquarium which combine suitable lighting intensities and water flow speeds. Since the upper region of the aquarium is often the preferred placement for high light corals, it is doubly advantageous to concentrate the fast water movement in the upper layers of the aquarium. Be mindful that when water flows around a shape, there is usually more turbulence and therefore more gas exchange on the downstream face of the shape. If you are looking at the upstream surface of a coral for indications of the coral's behavioral response to water flow, you could be missing the more significant response on the downstream face of a coral. The bottom line is that you should do a colony

Figure 1 This aquarium is a good example of a reef tank which uses a modest amount of live rock. Although it is a novel shape, the dimensions of this aquarium made it difficult to produce mass water movement.

wide inspection of your corals for indications of the suitability of the flow to which the coral is exposed.

Mass Water Movement

A moving mass of water will tend to return to a low energy, equilibrium state by way of several feedback mechanisms. Gravity, pressure, and friction are forces which ensure that the water at far ends of a vessel have a shared effect on the movement of the water mass as a whole. As aquarists trying to replicate flow conditions of the environment where corals occur naturally, we should be mindful of these forces and we should employ them to our advantage in order to encourage mass water movement throughout the entire aquarium.

In order to maximize the output of water flow equipment, aquarists should design water movement systems so that all the components work together to minimize resistance and move the entire water mass of the aquarium. The best way to combine the energy of moving water to produce maximum water motion for an aquarium is to encourage the formation of a circular course of water movement called a gyre. Like the wheel, a gyre takes advantage of feedback mechanisms which preserve momentum by minimizing resistance. An aquarium gyre somewhat resembles a conveyor belt of water movement and it is characterized by mostly laminar, unidirectional flow. By alternating the rotation of the gyre from one side to the other, it is possible to evenly distribute turbulence on all sides of corals and therefore increase photosynthesis and respiration. An extreme example of this technique is exemplified by a special aquarium called a gyre.

Gyre Tanks

A gyre tank encourages the maximum amount of water motion momentum because it contains a divider to essentially turn the tank into a circuit. This specialized aquarium constricts the cross section of the water's path so that all of the water is evenly moving in the same direction. A setup like this mostly dispenses with rock or other ornaments on one face of the divider so it reduces friction with the usual aquarium reef structure for at least one side of the flow's fetch. The divider stretches nearly the entire length of the aquarium and it can be placed either horizontally or vertically. In a vertical setup, the divider rests on the middle of the bottom of the aquarium and it projects out of the water surface. In a horizontal setup, the divider is flush with the middle of the front and back panes of the aquarium glass. A vertical gyre tank is good for keeping tall coral species such as gorgonians, arborescent soft corals and tall staghorn corals. This type of aquarium can be more aesthetic because it is easy to hide the pumps and flow outlets behind the divider of the aquarium and it preserves the viewing area of the tank. However, since the water mass of a vertical gyre is always in contact with the bottom of the aquarium and the surface of the water, it has more potential to develop velocity shear with faster flow at the top and slower flow at the bottom. In a horizontal gyre tank the powerheads or flow outlets are placed underneath the divider and they are aligned in a horizontal plane. This setup preserves the original actual surface area of the aquarium but it does so at the expense of the height of the aquarium. The larger surface area and closer proximity to the lighting source makes the horizontal gyre tank ideal for concentrated efforts of coral culture.

Figure 2 is an example of a horizontal gyre tank which I built for stony coral culture. The aquarium is 33 gallons, 4 feet long, 14 inches wide and 12 inches tall. The divider was made out of two pieces of dark plexiglass which were overlapped in the center. Both pieces of the divider were unattached and I found that I could vary the speed of the water flow by adjusting the distance of the gap between the divider and end faces of the aquarium glass. The water movement was provided by one Seio 820 pump on one side and two Maxi-jet 1200's on the other side. A Chauvet light timer was used to alternate power between the pumps for 5 to 15 minutes to each side. Since the water flow was so unidirectional in this long aquarium, it was very simple to measure flow speed. Water velocity was calculated by adding neutrally buoyant particles to the water and timing how long it took for them to travel across a distance of the aquarium. Using this technique I was able to measure water flow speeds between 15-22cm/s throughout the entire aquarium. These velocities are within the range of ideal flow speeds for optimum particle capture, respiration and photosynthesis of many corals. Figure 3 is an image of a vertical gyre tank built and designed my Michael Janes of Aquatouch. Mr Janes is an octocoral specialist and he refers to his design as a laminar flow tank. He designed the aquarium to produce ideal flow conditions while still maintaining enough vertical space to accommodate tall soft coral species such as gorgonians. Although this aquarium was designed primarily as a proof of concept, Mr. Janes continues

Figure 2 This horizontal gyre tank produced flow speeds between 15-22cm/s.

to work with this type of gyre tank for studying octocoral species.

Gyres in Reef Aquariums

An aquarium does not necessarily need a divider to produce gyres of the water mass. Although the water movement will not be as complete and uniform as it is with a gyre tank, it is still advantageous to encourage water movement to follow a circuitous path. In a reef aquarium with live rock and coral on the bottom, the water surface of the aquarium provides the least resistance to moving water. Because of the lack of friction, moving water which is directed in this region will produce the most momentum of the water mass. If there is an even transport of the surface water from one side of the aquarium to the other, the entire water mass should begin to gain momentum as it is moved at both ends. At one end of the aquarium, the water will begin to “pile up” and then sink down. At the other end, water will rise up to replace the volume which is displaced by the water motion. Although it is easiest to create gyres which follow the top and bottom surfaces of the aquarium, this is not the only way to create gyres. Figure 4 is a photo of a 180 gallon aquarium with an overflow drain right in the center of the tank. This aquarium contained a modest amount of live rock and it was circulated by encouraging mass water movement around the center overflow. Once again a Chauvet light timer was used to alternate the flow between two circuits of powerheads. Each circuit contained pumps which were diagonal to each other and in this fashion the force of both pumps were working together to move the entire water mass. The center overflow was not necessarily the most aesthetic design but it was very easy to spin water around it using only very modest water pumps.

Not only can mass water movement techniques help aquarists produce higher water flow speeds in the aquarium but it can also encourage more water movement through the interstices of live rock and corals with open growth forms. Normally an aquarist might target one or more plumes of water movement at corals which require fast water flow speeds. In this scenario, the turbulent water flow plume encounters a lot of friction on its way to the desired location of the reef aquarium: it will experience resistance from the still water around it, it will experience drag from the shape of the corals it encounters and the turbulent nature of the water flow plume will do little to preserve the momentum of the water movement. In a scenario with the employment of mass water movement, the behavior of the fluid will be much different. The plume of water motion from the same source will encounter less resistance from the water around it since both parcels of water are moving in the same direction. The decreased resistance will straighten out the flow and preserve more momentum. Not only will the water be moving faster

Figure 4 Because this 180 gallon was circulated using mass water movement techniques, only modest equipment was required to produce adequate water motion.

Figure 3 A vertical gyre tank (a.k.a. laminar flow tank) designed to accommodate tall coral species. Photo by Michael Janes.

Figure 5 An example of a mature reef aquarium which exhibits very dense stony coral growth.

once it reaches a coral, since water is moving away from the coral on the downstream end, water will be forced through the normally stagnant water which is present at the interior of corals with open growth forms. Figure 5 shows an aquarium where dense coral growth account for a significant portion of the aquarium's cross section. When using mass water movement techniques in cases of dense coral growth, water flow speed can actually accelerate as more water is pushed through spaces with a smaller area. Aquarists who wish to encourage additional water movement at the inside of dense coral colonies will see great benefits from using mass water movement techniques.

Conclusions

The reef aquarium hobby has a long way to go before our understanding of water flow catches up with what we know about reef aquarium lighting. Like the "Watts per Gallon" moniker that came before it, the use of "turnover rate" to describe water movement continues to cripple the progress of more advanced water movement techniques. By encouraging the formation of one or more gyres, aquarists are capable of producing more water movement in terms of overall water flow speed. Since higher flow speeds produce greater amounts of turbulence, this translates into increased gas exchange and higher rates of photosynthesis and respiration.

References

1. Harker, R. 1998. Measuring Turbulent Flow in Reef Tanks. Aquarium Frontiers, August Issue.
2. Janes, M.P. 2005. ANew Era for Sea Fans? International Marine Aquarium Conference. Chicago, Illinois.
3. Riddle, D., 1996. Water motion in the reef aquarium, Part 1. Aquarium Frontiers, 3:4, 32-39.