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Chapter 13

Current in aquaria, best way to create

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ABSTRACT
Laminar or turbulent currents are of great importance for healthy growing corals, providing nutrients and removing metabolites. Aquarists generally agree on installing enough pumping power to create current in the tanks. One rule of thumb is to pump at least 10 tank volumes per hour - so the unit is $L.h^{-1}$ or $m^3.h^{-1}$. But is this unit adequate for the problem of creating current in tanks? Especially for larger tanks the above rule of thumb is very difficult to apply. Physically, currents are described by their velocity (in $m.s^{-1}$) and additionally by the body of water (in kg) which is flowing and by the direction of the flow. So what is the appropriate unit to look at if we want to create or increase currents in aquaria? The answer is thrust! This answer was found several years ago and was confirmed when later on the same thinking was found to be applied to the mixing process of waste water treatment plants. The unit of thrust is $(kg.s^{-1}) * (m.s^{-1})$ or $kg * (m.s^{-2})$ = N (Newton) which is also the dimension of force. If the current is described by the momentum $kg * (m.s^{-1})$ the thrust can be considered as the input of momentum to the system. And with this it makes a great difference if a certain amount of water is released by the pump with a high or low velocity. Not $l.h^{-1}$ is what counts but $l.h^{-1}$ * velocity. At the first glance high velocities seem to be favorable, but a more detailed discussion will show that large volumes pumped at low velocities are much more efficient.

INTRODUCTION

Coral reefs are located in warm, nutrient poor water, in the deserts of the sea. Currents are of great importance because they provide nutrients, remove metabolites and sediments. So it is obvious that it is necessary to create currents also in aquaria housing living corals. Water velocities in the range of 10 - 30 $cm.s^{-1}$ are necessary for many filter feeders or give increased growth rates (Schutter *et al*., 2007). The benefits for aquaria are very well described (Adams, www2). Furthermore, Michalek-Wagner (pers. com.) states that 3 - 6 $cm.s^{-1}$ is not enough water velocity inside aquaria.

In most cases pumps are used which are characterized by the water flow at a certain head. But up to now there is no general and reliable way to connect these data to the currents inside the tanks.

This paper will show what parameters are important to describe currents and to increase currents independent of the way how this is done. In the next step these parameters will be connected to existing recommendations showing that these recommendations are only a small part of many possibilities to create appropriate currents in the tanks. The relation to consumption of electricity power and to stress on planktonic organisms in the water is shown.

Current

Physically current or water flow is described by the mass of the flowing water and the velocity of the water. The velocity normally consists of the magnitude of the velocity and the direction of the velocity. As water does not have a rigid body but is able to quickly change it´s form and flow direction only the magnitude of the water velocity is of importance for the following considerations.

So a current or water flow is described by it´s mass (m) and velocity (v) which is:

formula 1

p (momentum) = mv $\left[kg * \frac{m}{s}\right]$

By friction there is a permanent loss of the momentum inside the aquarium and this loss has to be compensated by a pump or any other device creating water flow. So it is necessary to permanently add momentum to the tank. And the input of momentum to the aquarium is: thrust (T)

formula 2

$$T = \frac{\Delta p}{\Delta t} = \frac{\Delta m}{\Delta t} * v \qquad \left[\frac{kg}{s} * \frac{m}{s} = N\right]$$

N = Newton

Thrust is a common unit for the propulsion of ships (Menny, 2003) and aeroplanes and is in the meantime also used to calculate the mixing process in the biological treatment process (www1) in waste water plants. This application is very similar to creating currents in aquaria besides that there are no heavily structured reef imitations in the waste water basin. Thrust (T) has the same dimension as the force (F).
The formula 2 shows that thrust is the amount of water per time multiplied with the associated velocity.

Applied to a normal pump: the thrust that the pump produces is the water flow in $L.s^{-1}$ or $m^3.h^{-1}$ multiplied with the velocity of the water at the pipe outlet into the tank (as water has a specific weight near 1 $kg.L^{-1}$ the mass [kg] is simply substituted by the volume [L]).
At first view this suggests to simply reduce the diameter of the pipe outlet to increase the velocity of the water. This is right to increase the thrust with existing pumps.

Thrust

As thrust is a product of water flow multiplied with the velocity of the water there are many ways to create thrust. A fixed amount of thrust may be reached either with a low water flow combined with a high velocity or with a high flow rate and a low associated water velocity. Figure 1 shows the relation at a constant thrust of 10 N.
The water flow rate ($\dot{V}$) is thrust (T) divided by the outlet velocity (v):

formula 3

$$\dot{V} = T / v$$

In this example always the same thrust is created but there are big differences in the required electrical power consumption and in the energy input into a certain amount of water. This last point is important if planktonic organisms shall survive in the water. The following formulas

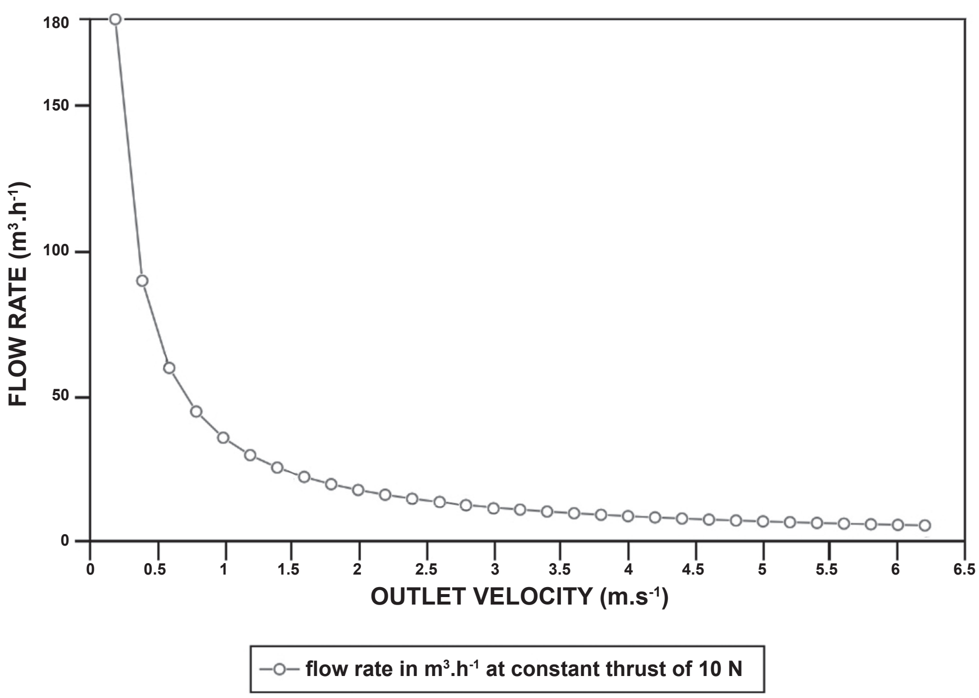

Figure 1: Flow rate against outlet velocity at the same constant thrust of 10 N. High flowrates are combined with low outlet velocities and low flow rates are combined with high outlet velocities.

will prove this conclusion:
Moving water has kinetic energy (E_k) which is:

formula 4

$$E_k = \frac{m}{2} * v^2 \qquad [\, kg * m^2.s^{-2} \,]$$

and the theoretically required power (P) to induce a certain water flow at a certain velocity is:

formula 5

$$P = \frac{m}{2t} * v^2 \qquad [\, kg.s^{-1} * m^2.s^{-2} = W \,]$$

Therefore:

formula 6

$$P = \frac{T}{2} * v \qquad [\, W \,]$$

and this formula (6) shows that if the thrust is constant the required power to induce this thrust increases with the velocity. This is easy to understand because the velocity is linear in thrust and quadratic in power.
The result is that for the same thrust at 6 $m.s^{-1}$ the required electrical power is six times the value as at 1 $m.s^{-1}$. Hence it would require a higher investment for a bigger motor and six times higher running costs. This relation is shown in Figure 2.

The second argument for a low velocity in creating thrust is the input of energy into a certain amount of water. The higher the input of energy into the water is the more will planktonic organisms be damaged by shear forces. The energy necessary to accelerate 1 L of water to 1 $m.s^{-1}$ is 0.5 W, but to accelerate it to 6 $m.s^{-1}$ at least 18 W are needed. And this means high stress and damage for many plankters.
Because corals benefit from feeding (see also Chapter 2, 3 and 4) it is an advantage to create currents inside aquaria destroying neither food organisms nor planctonic organisms that grow somewhere in the tank or an adjacent refugium (Adey and Loveland, 1998). If currents are created in a plancton friendly way food chains based on bacteria and microalgae may develop inside aquaria. Additionally even many benthic organisms including corals have gametes or larvae that are plankters for some time. These gametes or larvae would also benefit from a low shear creation of currents.

Required thrust in aquaria

How much thrust is required to get enough current inside an aquarium?
For smaller coral reef tanks like tanks behind the scenes or for private tanks a rule of thumb is to pump at least ten times the tank volume per hour. For diplay aquaria a recommendation is 114 – 454 $L.h^{-1}$ at 3.05 – 6.10 $m.s^{-1}$ for each 379 L of display water

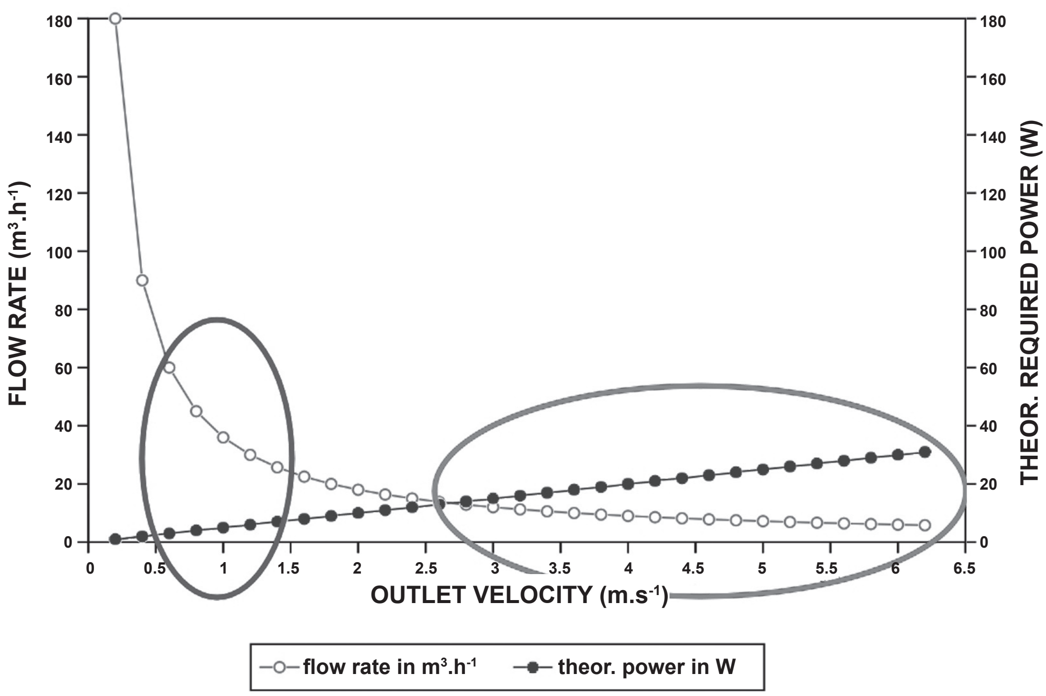

Figure 2: Flow rate and theoretically required power against outlet velocity at the same constant thrust of 10 N. Outlet velocities around 1 $m.s^{-1}$ are especially advantageous because they have only low power requirements and create low shear and low damage of planctonic organisms. Outlet velocities above 2,5 $m.s^{-1}$ should be avoided in new installations.

(Yates, 2004). From this recommendation the thrust can be calculated and the first rule of thumb is based on usual power head pumps.

If the data of the standard powerhead pumps are combined with the rule of thumb (10 tank volumes per hour) this would lead to a new recommendation of at least 10 N of thrust for 1,000 L of tank volume.

And now, it is easy to understand why many aquarists have been disappointed when installing a 6,000 $L.h^{-1}$ stream pump instead of a conventional 3,000 $L.h^{-1}$ powerhead pump: the thrust of the stream pump is only half of that of the powerhead pump (compare Table 1).

The recommendations of Yates are much lower than the above rule of thumb: 0.26 to 2.03 N for 1,000 L of tank volume.

Of course large display tanks differ from small tanks in many ways. The relation of the water volume relative to the amount of natural or artificial rocks and its surfaces increases with tank volume. Therefore the loss of momentum by friction decreases with increasing tank size. But as 10 N for 1,000 L tank volume is the minimum thrust for smaller coral reef aquaria I expect 5 N for 1,000 L tank volume to be a minimum requirement even for larger display tanks if sufficient current shall be created for live and healthy corals.

With the new parameter thrust a tool exists that allows a better comparison of different current creating systems and also allows a more accurate description of existing coral reef tanks to gain better experience from them. The knowledge of thrust will help to improve the environment of corals in captivity.

Practical implications

An example of creating high thrust with low velocities is demonstrated by Gerostiga and Gerostiga (unpubl. results). They use a water wheel to create a very high water flow with low velocity and they point out the very low energy costs of this system. This result is totally consistent with the above theory.

If new tanks with living corals are planned the system to create the appropriate currents in the tank should gain special attention. Conventional pumps are in many cases not the best choice because of energy consumption and the created shear force on planktonic organisms.

Items such as the waterwheel may be considered as alternatives. Another alternative may be mixers as they are used at the reef tanks at the Reef HQ in Townsville (see Chapter 9) and at Burgers' Ocean in Arnhem (see Chapter 31) EMU/WILO etc., although there may be some problems with the material of stainless steel in combination with anodes of magnesia to prevent corrosion.

Table 1: Thrust generated by different pumps and the recommendations of Yates (2004)

Pump	Flow rate acc to manufacturer ($L.h^{-1}$)	Diameter of outlet (mm)	Thrust (N)	Outlet velocity ($m.s^{-1}$)
aquabee UP 3000	3,000	16	3.45	4.14
Tunze Turbelle 7400/2	4,000	22	3.25	2.92
Tunze stream 6060	6,000	47	1.60	0.96
Tunze stream 6100	12,000	47	6.40	1.92
Tunze stream 6200	20,000	59	11.29	2.03
Tunze stream 6300	30,000	59	25.40	3.05
for each 379 L exhibit volume (Yates, 2004)	114		0.10	3.05
for each 379 L exhibit volume (Yates, 2004)	454		0.77	6.10

Possibly new current creating items will occur in future. In many existing coral reef tanks conventional pumps are used to create the currents inside the aquaria. Often these setups allow an improvement of the thrust. Figure 3 shows the typical curves to describe such a pump.

Head against water flow rate; power consumption, the NPSH-value (NPSH = Net Positive Suction Head is the lowest required water head or pressure on the suction side of the pump to prevent cavitation, bubbles, vibration, noise and headloss) and the efficiency of the pump. It is easy to see that such pumps are not build to produce very high flow rates ($m^3.h^{-1}$) with nearly no head. In this example flow rates above 32 $m^3.h^{-1}$ should be avoided because the NPSH-value increases too much. The way to increase thrust with such a pump is to reduce the outlet diameter of the pipes. By this the velocity of the water increases although the flow rate decreases a little bit. But this has to be done carefully and by trial and error and the result depends on the specific head versus flow rate graph of the applied pump:

1) Measure or calculate the present cross section surface of the pipe outlet. Measure the pressure (pressure gauge) in the pipe behind the pump. In doing so, you get the present working point of the pump i.e. the present water flow from the pump specific head versus water flow graph. Now the present thrust can be calculated.

2) Reduce the cross section surface of the outlet pipe carefully, for example with a piece of pipe with the next smaller diameter, read the pressure gauge and look at the graph to get the associated water flow. Calculate the new thrust regarding to the new outlet area and the new flow rate.

3) Repeat step 2) until no further increase in thrust can be achieved.

In the present example a decrease in flow rate from 32 down to 28 $m^3.h^{-1}$ gives an increase of head from about 10 up to 16 m to overcome a smaller cross section surface. This will probably generate higher outlet velocities with only a small loss in flow rate i.e. more thrust is generated.

CONCLUSION

Thrust, which is a new parameter for the field

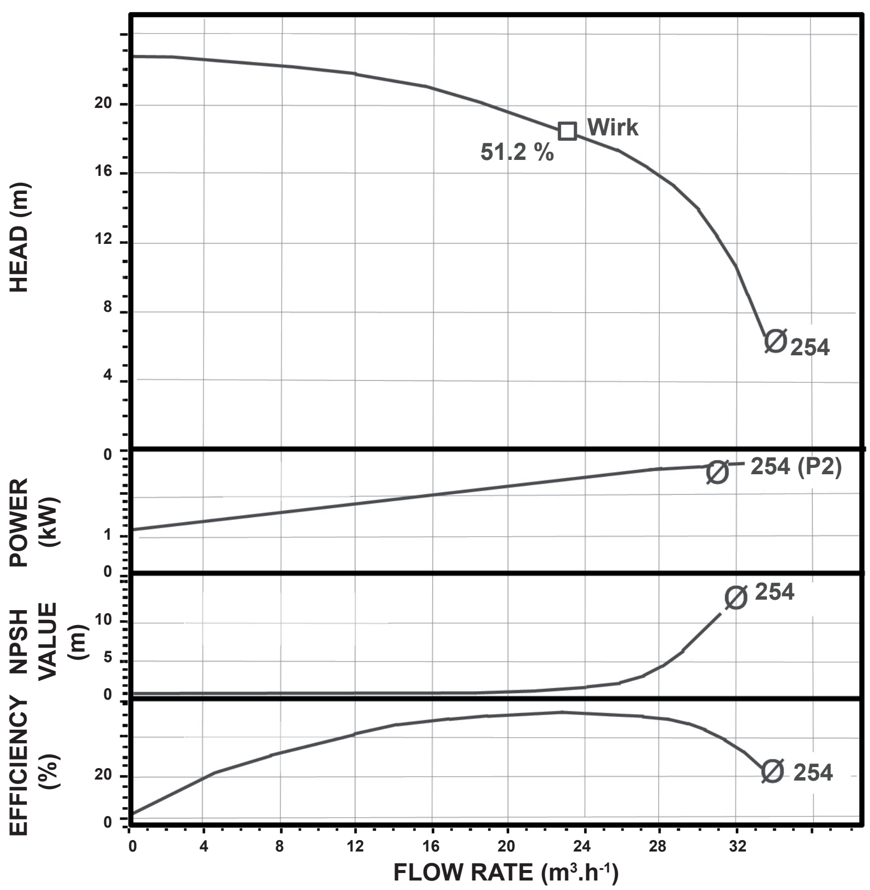

Figure 3: Typical information provided with a standard pump. Often only the head versus flow rate graph is provided and a minimum NPSH value. See text for more details.

of aquaria, shows the potential to improve the husbandry of corals, which have a specific and high need for artificially created currents when kept in aquaria. This need can be fulfilled in many different technical ways, but thrust is the independent parameter to estimate the influence of different technical equipment in creating currents. On the other side, a given or planned tank has a certain demand for thrust and by this the appropriate technique can be chosen.

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