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# Observations of flow patterns in a model of a marine fish larvae rearing tank

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ABSTRACT

There are few studies on flow fields generated by aerators in fish larvae rearing tanks. The flow varies with aeration rates and tank proportions resulting in different larvae survival rates. The effects of aeration rate and aspect ratio *AR* (the ratio of liquid depth to tank radius) on overall flow patterns were investigated experimentally using flow visualization techniques. Two distinct types of flow patterns, a single-pair vortex system and a two-pair vortex system, were observed as the value of tank aspect ratio varied from about 1.0 to 2.0. In addition, corner vortex structures were observed in both the region between the free surface and the upper sidewall, and between the bottom wall and the lower sidewall of the tank. On the sidewall, reattachment and separation points were found, which were closely related with these vortex structures.

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## 1. Introduction

One of the most important issues in larval rearing of marine fishes is mass mortality during the initial stage of larviculture, referred to as early mortality. The principal causes of early mortality in the wild include starvation, predation, and transportation to unsuitable physical conditions of water (Houde, 1987). Control of the physical environment is an important element in fish rearing and controlling the flow in a rearing tank with aerators is often used. However, since this is usually managed by fish culturists guided by their experiences and direct observations of the water of flow, this empirical knowledge varies somewhat among these fish culturists. Furthermore, mass mortality can occur as a result of even slightly improper aeration settings. For example, too strong aeration is suspected of leading to mass mortality by hindering larvae feeding and causing them to expend excessive energy to maintain their position (Tucker, 1998). On the other hand, if aeration rate is insufficient, the flow in the central part of the vortex becomes mostly 'dead water' which is unsuitable for the rearing of larvae, suggesting that some optimum aeration rate should exist (Shiotani et al., 2003). Given these points, ensuring the appropriate physical environment for marine fish larviculture is a crucial factor for providing basic insights into the development of larviculture techniques. Specifically, we need to accurately understand the flow field in the rearing tank to enable the creation of appropriate flow patterns corresponding to the actual rearing scale, as well as to perform simulations of velocity distributions applicable to different tank proportions and volumes. Achieving these goals will promote the effective control of the flows in rearing tanks using aeration.

Previous studies on the flow fields in rearing tanks simply measured the flow in small-scale rectangular tanks, and also investigated the effects of aeration rate (Backhurst and Harker, 1988), but there have been very few systematic measurements of the flow field itself within the tank. Recently, a series of studies quantitatively investigated the flow field in tanks rearing larvae of the seven-band grouper *Epinephelus septemfasciatus* (Shiotani et al., 2003, 2005; Sakakura et al., 2007) that used circular tanks with volumes of 1 $m^3$ and 100 $m^3$. In these studies, the tanks had aspect ratios (*AR*) of less than 1.0. The flow was measured with an ultrasonic velocity meter for vertical cross-sections through the central tank axis. The occurrence of the vertical circulating flow in the cross-section was then quantified. The relationship between the flow field established by aeration and the survival rate of larvae was also compared through larval rearing experiments using similar tanks, and the optimum

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**Table 1**
Mean survival rate of seven band grouper and devil stinger in rearing tanks to aspect ratio (*AR*).

| Aspect ratio (*AR*) | Survival rate (%) |
|---|---|
| 0.74 | 5.3–7.3 |
| 1.36 | 4.6–7.3 |
| 3.29 | 16–36.4 |

flow field for larval rearing was obtained for every scale of tank (Shiotani et al., 2003; Sakakura et al., 2006, 2007). However, given the measurement principles in use with the ultrasonic velocity meter, the flow velocities near the vicinity tank wall and the free surface were not measured in these studies.

Ruttanapornvareesakul et al. (2007) carried out a series of larval rearing experiments for the seven-band grouper and the devil stinger *Inimicus japonicas* (Cuvier). Three types of circular tanks were used in these studies with an aeration rate ($Q$) of 50 mL/min, a constant water volume of 0.1 $m^3$ for three types of circular tanks where the tank radius and liquid depth varied. Survival rates of the seven-band grouper larvae and devil stinger were higher in tanks with a smaller diameter and greater liquid depth (i.e., larger *AR*), and behavioral observations revealed that the number of so-called 'surface tension-related deaths', in which larvae are captured by the surface tension and die, was smaller for tanks with smaller free surface areas. Unfortunately, these studies did not investigate how the flow within the tank and the distribution of the larvae were related.

If the flow within the vertical cross-section of a circular tank is treated as a two-dimensional symmetrical flow, it may be compared with the interior flow of a two-dimensional channel. Many studies have examined flow fields in the interior of a channel as rough surface flow for either a single channel or consecutive channels, treating them as cases of two-dimensional wall surface flow (Tani et al., 1961; Kameda et al., 2004, 2005). Among these, Tani et al. (1961) reported that the flow over the channel changes significantly for a ratio of channel depth to width in the vicinity of 0.7 based on surface pressure and velocity distribution measurements of the channel interior. According to these results, the flow pattern may be changed by altering the *AR* of rearing tanks. If the flow pattern in the tank can be examined in detail and controlled, it may be possible to better understand how the flow may have affected survival rates in the rearing experiments of Ruttanapornvareesakul et al. (2007) mentioned above. The circular tanks used in the above-mentioned experiments of Ruttanapornvareesakul et al. (2007) were made of polycarbonate (SPS-200, SPS-100 and SLP-100, Tanaka Sanjiro Co., Ltd., Fukuoka, Japan) and were of a shape whose diameter increased slightly from the bottom surface upward. For convenience, the *AR* was calculated after finding an average tank radius from the volume of water and liquid depth; those *AR* values were respectively 0.74, 1.36, and 3.29. The survival rate results of their experiments are shown in Table 1. These results suggest that the flow pattern may have changed markedly as the *AR* changed from 1.36 to 3.29.

In light of these considerations, this study examined the flow pattern under varying $Q$ and tank *AR*, using flow visualization over a wide region which extended to the immediate vicinity of the free surface, the bottom wall surface, and the sidewall surface. From the flow patterns obtained, the vortex structures and why they arise were investigated with the objective of improved control of the flow field in rearing tanks.

This paper uses several terms from the field of fluid dynamics, defined here. A *vortex filament* is often just called a vortex, but this term will be used to denote any finite volume of vorticity immersed in an irrotational fluid (with obvious modifications when the flow is two-dimensional) (Saffman, 1993). *Separation point* is the position

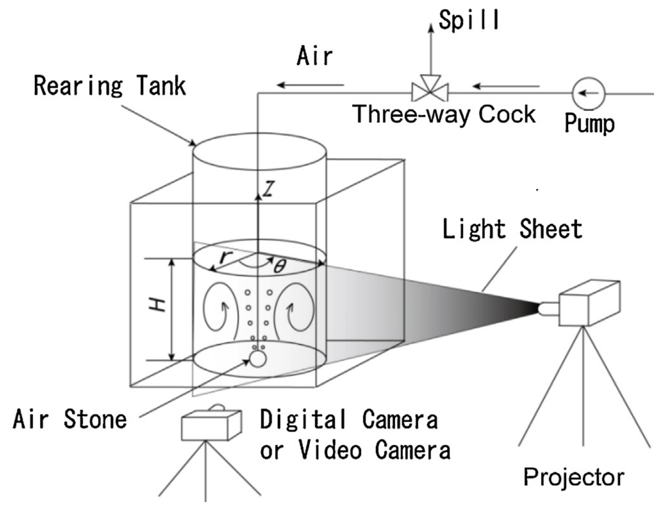


**Fig. 1.** Experimental apparatus and the coordinate system. The cylindrical coordinate system is used, with the radial, azimuthal, and vertical directions expressed as $r$, $\theta$, and $z$, respectively. Definition of aspect ratio (*AR*) is $H/r_i$, where $H$ is the liquid depth and $r_i$ is the internal radius of the tank.

within the boundary layer where the shear stress at the wall is kept equal to zero (Tennekes and Lumley, 1994).

## 2. Materials and methods

### 2.1. Experimental apparatus

A circular tank was used in the experiments with the following dimensions: internal diameter $2r_i = 390$ mm, external diameter 400 mm (5 mm thickness), and height 590 mm. The tank was made from transparent acrylic resin. The tank used for experiments was largely static (i.e., no water inflow). Since the fluid inside the tank was only for observation of the flow pattern, tap water was used. In order to avoid distortion by refraction of the transmitted light in the visualization experiments, a rectangular tank was installed around the exterior of the circular one, which had a cross-section of 500 mm × 500 mm and a height of 500 mm, and the gap between them filled with water. Fig. 1 shows the experimental apparatus and coordinate system. The experiments were divided into three types corresponding to the quantity of air flow rate introduced (aeration rate) $Q$ of 10, 25, or 50 mL/min. The relationship between air rate $Q$ and volumetric aeration time (*VAT*) is shown in Table 2. *VAT* is defined as the ratio of rearing tank volume to airflow rate. The term is used for comparisons between different tank sizes (Cornacchia and Colt, 1984). Air was diffused in the tank using a spherical air stone made of porous ceramic (20 mm in diameter; Global 20, Tanaka Sanjiro Co. Ltd., Japan). Air rate $Q$ was controlled by the quantity of air supplied by an air pump (Techno Takatsuki, SPP-6GA) using a three-way cock to regulate aeration rate. Aeration rate values were obtained by averaging several measurements of the disgorged quantity of air per minute, collecting the air directly with a beaker in the tank. The liquid depth was varied according

**Table 2**
The relationship between air flow rate $Q$ (mL/min) and the volumetric aeration time *VAT* (min) for tanks of varying *AR*.

| $Q$ (mL/min) | *AR* | | |
|---|---|---|---|
| | 0.5 | 1.0 | 2.0 |
| | *VAT* (min) | | |
| 10 | 1164 | 2328 | 4657 |
| 25 | 466 | 931 | 1863 |
| 50 | 233 | 466 | 931 |

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