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Numerical Simulation of Three Dimensional Flow in Water Tank of Marine Fish Larvae

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Summary

Marine fish larvae are fragile against physical stress. However, few studies have been conducted to evaluate the flow field in a rearing tank, which is assumed to provide a high degree of physical stress to marine fish larvae.

This paper is a report on the numerical estimation of stationary flow in the rearing tank of marine fish larvae. The calculated flow in the rearing tank was compared with the experimental one. The calculation of the stationary flow in the rearing tank showed good qualitative and quantitative agreement with the experimental results.

Introduction

Recently, the culture of marine fish has been developed and growth of many kinds of fish larvae has succeeded by improvements of culture technique. However, marine fish are fragile; physical stress such as unfavorable flow, light, water temperature and etc, may result in mass mortality of larvae. Among fish species, grouper larvae are highly sensitive to physical stress and mass mortality is caused by floatation in the rearing tank after hatching of eggs. It was thought that the flow in the rearing tank gave the most effective impact to grouper larvae with small size.

In general, the flow in the rearing tank was generated by aerators, which were commonly used to provide oxygen as well as aid in the even distribution of live food. However, few studies have been conducted on the flow field in the rearing tank [1]. Authors reported the systematic experiments of flow measurement and rearing seven band grouper *Epinephelus Septemfasciatus* using 1m^3 polyethylene rearing tank [2].

The estimation of flow in the rearing tank using a flow meter is very important against the examinations of larvae growth and mass mortality caused

by floatation. However, as the comfortable circumstance of flow in the rearing tank is different for each kind of larvae, the measurement of flow each time is not effective for time and economy.

This paper deals with estimation of flow in the rearing tank of marine fish larvae by a numerical computation method. The results from such studies may be very useful for the purpose of flow estimation in the rearing tank and in the design of larval rearing tanks.

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Numerical Calculation of Flow

For the purpose of estimating the stationary flow in the rearing tank, a numerical computation was conducted. The numerical computation of three-dimensional flows of the tank was carried out. The dimensional governing equations were the three-dimensional incompressible Navier-Stokes equations (1, 2 and 3) and the continuity equation (4) as follows:

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+\nu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right) \tag{1}$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial y}+\nu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right) \tag{2}$$

$$\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial z}+\nu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right) \tag{3}$$

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \tag{4}$$

where the origin in the Cartesian coordinates system was placed at the center on a free surface of rearing water tank and (x,y,z) represented the axis in radial and upward directions respectively. The velocity components were (u,v,w), p was the pressure in the water, ρ was the water density and ν was the kinematic eddy viscosity.

The calculation of flow in the rearing water tank was made by the finite differential method using MAC scheme. The time differentials in Eqn. (1), (2) and (3) were expressed by the first forward difference, namely the Euler explicit scheme. The second order central differences were used for the spatial differentials in Eqn. (1), (2) and (3). Keeping the numerical computation stables, the convection terms were evaluated by the third order upstream difference. The Poisson equation for obtaining the pressure term was solved by the SOR method.

The calculated scheme of flow in the rearing water tank was made by the curvilinear coordinate systems for the purpose of calculating flow near wall and free surface in the water tank in detail as follows:

$$\begin{aligned}\xi &= \xi\left(x,\ y,\ z\right)\\ \eta &= \eta\left(x,\ y,\ z\right)\\ \zeta &= \zeta\left(x,\ y,\ z\right)\\ \tau &= t\end{aligned} \tag{5}$$

In general, the calculation of flow in the circular cylindrical water tank, is made by the cylindrical coordinate system, it is possible to calculate of flow in an arbitrary water tank profile.

Calculated Results

Fig. 1 shows a $1m^3$ polyethylene tank for investigating the effects of flow in a rearing tank on mass mortality in the initial stage after hatching of seven band grouper, experiments of rearing larvae. The rearing tank was cylindrical with a 154cm diameter at the top and a height of 82cm. The flow in the rearing tank was generated with a typical spherical aerator with a diameter of 5cm placed at the bottom center of the rearing tank.

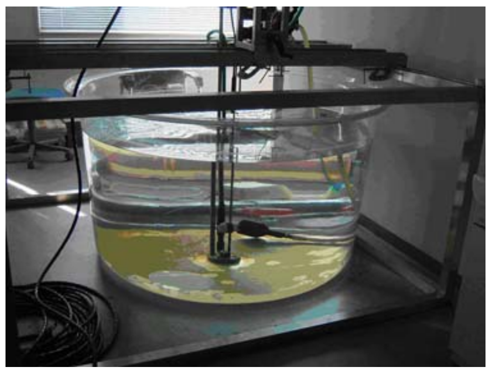

Figure 1: Rearing tank for experiments of rearing larvae

In the experiments of rearing larvae, four aeration rates were proposed. The numbers of dead larvae on the water surface in the tank were counted everyday. The results of rearing experiments were compared under each set of different aerating rate, in addition, the effects of the various aeration rates on survival and larva deaths, according to the number dead and floating, were investigated.

From the measured results of the experiments of rearing tank larvae, the survival of larvae was very high in the initial stage after the hatching of eggs in tanks with an aeration rate at 200ml/min.

The measurements of stationary flow by aerating in the rearing tank generated by an aeration were carried under the condition of the rearing rate at 200ml/min. The flow in the rearing tank was measured at each positions in the half plane of vertical section included the center of water tank. The mean velocities of three components (u, v, w) of flow in the rearing tank were obtained from sampling data.

From the results of the experiments of rearing, the estimation of flow in the tank for an aerating rate of 200ml/min was carried out by numerical calculation. The calculated flow in the rearing tank was compared with the experimental one. Fig.2 shows the grid topology of the calculated region in the rearing water tank. The number of grid points was 30×30 in the (x, z) vertical plane and 30×70 in the (x, y) horizontal plane. The grid spacing was clustered to wall, water surface plane and the center of the rearing tank.

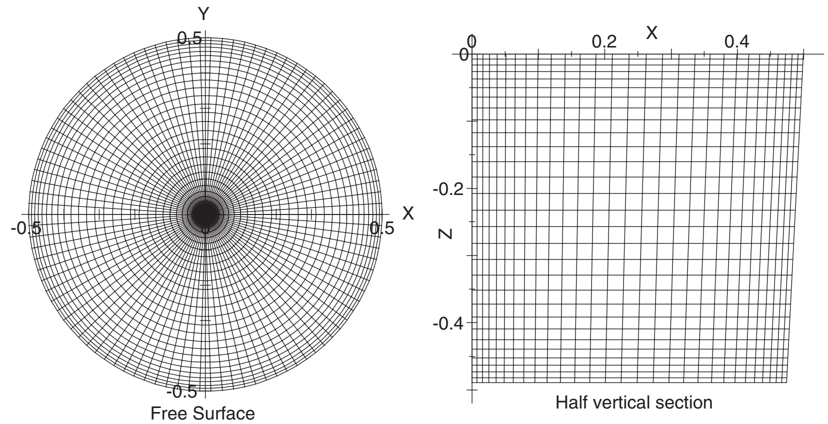

Figure 2: Grid topology of a rearing tank

Boundary conditions in the computational domain were as follows. On the bottom and sidewall boundaries, the no-slip condition was implemented. At the center of the rearing tank boundary, the mean flow obtained from the measured flow was implemented because the relation between the aeration rate and the distribution of the flow velocity was not fully known. On the free water surface condition, it was assumed that the free surface elevation was fixed and the velocity component of w was zero, because the weak aerating rate was not almost caused the variation of the free surface elevation. The Reynolds number based on the diameter of rearing tank and the strongest mean velocity generated by aerating on the center line in the rearing tank was about 1.0×10^5 order.

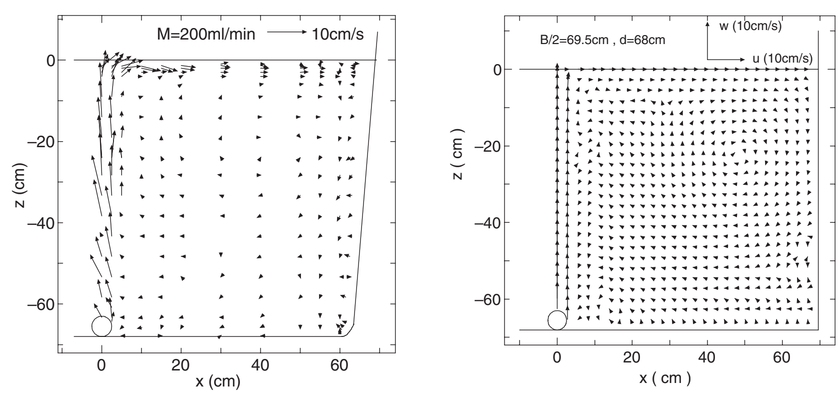

Figure 3: comparison of the calculated and experimental velocity distributions

Fig.3 shows comparison of the calculated and experimental velocity distributions on the vertical section including the center of the tank in the rearing tank flow velocity distribution. The figure on the left shows u-w velocity distribution on the measured vertical section (x, z). and the remarkable vertical circulation was observed. The figure on the right shows calculated u-w velocity distribution. A comparison of the experimental and calculated results indicates that the computational method herein presented can be used to satisfactorily represent the stationary vertical circulating flow.

Fig.4 shows the comparison of calculated and experimental velocity distributions on the vertical and horizontal lines including the center of vertical circulation. Both velocity distribution were very similar quantitatively.

The calculation of the stationary flow in the rearing tank showed good qualitative and quantitative agreement with the experimental results. The numerical estimation of the flow in a rearing tank of marine fish larvae was confirmed to be effective and satisfactory for the design of a tank that would provide optimum performance

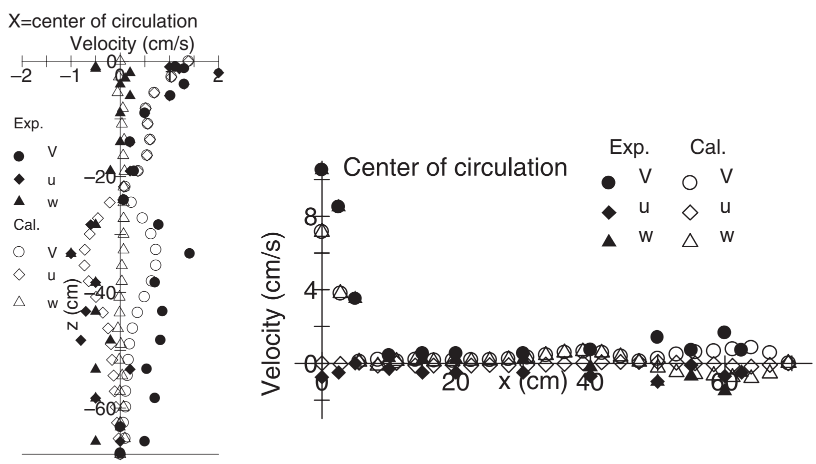

Figure 4: comparison of calculated and experimental velocity distributions

Conclusion

Three dimensional calculations can be used to estimate the flow in the vertical section of the rearing tank, including the center of the tank. Comparing the experimental and calculated results, the stationary vertical circulating flow was satisfactorily represented by numerical computation method of three dimensional curvilinear coordinates system proposed in present paper. Both velocity distributions are in good agreement. Also, both locations of the center of the vertical circulating flow were very similar.

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