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Numerical Analysis of a Hydrocyclone in a Recirculating Aquaculture System

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Abstract

This study investigated the performance of a vortex hydrocyclone for solid removal in a recirculating aquaculture system. In a fish-breeding industry, effluent water is mainly disposed by gravity sedimentation. Thus, a large settling tank and a lot of water are needed to purify effluent water. However, this typical method does not show consistent efficiency. In case of low efficiency, discharged water contains a lot of feeding sediments. This causes environmental problems. Instead of this typical method a hydrocylone is tested to discharge water which contains a lot of feeding sediments. In this paper, a hydrocyclone with low velocity and pressure drop in a recirculating aquaculture system is investigated.

Introduction

A recirculating aquaculture system is used to purify contaminated water in a fish breeding nursery. The disposal of effluent water in an aquaculture system depends on gravity deposition. This system requires a large amount of water and a large installed area. The efficiency of this system varies with respect to different aquaculture systems. Exhausted water with low separation efficiency produces an adverse effect to the environment due to the release of wastages and fecal solid to environment. A sediment tank with a hydrocyclone can not reduce the installed area of a tank compared to the typical system, but expect a stable efficiency. This means that applying a vortex hydrocyclone in a recirculating aquaculture system is more effective than the traditional system. Also, the method of removing excrements of fish in a fish nursery industry can protect environment.

Madhumita et al. [8] studied the separating efficiency of particles in a gas cyclone with a commercial size. In case of the particles with a diameter below 0.5 µm, they suggested a good design to develop an active swirl in a flow. Dia et al. [3] performed a numerical analysis on the sample of a hydrocyclone with a diameter of 40 mm. They presented the results of inside flow in a cyclone, because a cyclone's efficiency depends on a swirl flow. Franchon and Chlliers [5] studied a flow pattern and a separation efficiency in a gas cyclone numerically. They researched on particles of size 1-3 µm and compared with experimental results. Dirgo and Leith [4] performed an experimental study for two cases of cyclone; the first cyclone has a fluid guide vain along a tangent line, the second case has the shape of creating a vortex by a guide. Mothes and Loffer [9] conducted an experiment with a cyclone extensively for a laboratory test. They measured velocity components in three-directions using LDV and studied particles which were being separated into gas and solid forms. Griffiths and Boysan [6] compared the methods presented by previous researchers. They presented a flow pattern and analysed a cyclone's efficiency with respect to particle movement.

The previous studies mostly investigated patterns of flow in a high velocity and pressure drop situation. On the contrary, present paper investigates the fluid flow in a low velocity and pressure drop in a large system. In addition to this, current study deals with a variation of a fluid flow and separation efficiency in a recirculating separation devices particularly used in an aquaculture system.

Mathematical model

Because a real geometry of a hydrocyclone is complicated, the geometry is simplified for computation (see Figure 1). The assumptions to analyze the flow characteristics of a vortex separator are in the following: The flow is three-dimensional and incompressible, viscosity and density of a fluid remain constant, and a buoyancy force is negligible.

For a numerical simulation of a hydrocyclone, the governing equations in tensor notation can be written as follows:

$$\frac{\partial u_i}{\partial x_i} = 0 \tag{1}$$

$$u_j \frac{\partial u_i}{\partial x_j} = (\nu + \nu_t) \frac{\partial}{\partial x_j}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) - \frac{1}{\rho}\frac{\partial p}{\partial x_i} \tag{2}$$

$$\nu_t = C_\mu \frac{K^2}{\varepsilon} \tag{3}$$

Here, u_i is the velocity, p is the pressure, the ranges of I and j are from 1 to 3, ρ is density, and ν is dynamic viscosity.

A RNG $k-\varepsilon$ model is used due to strong swirl flows. The transport equations for the kinetic energy of turbulence and its dissipation rate are

$$u_i \frac{\partial K}{\partial x_i} = \frac{\partial}{\partial x_i}\left(\frac{\nu_t}{\sigma_\varepsilon}\frac{\partial K}{\partial x_i}\right) + P + G - \varepsilon \tag{4}$$

$$u_i \frac{\partial \varepsilon}{\partial x_i} = \frac{\partial}{\partial x_i}\left(\frac{\nu_t}{\sigma_\varepsilon}\frac{\partial \varepsilon}{\partial x_i}\right) + C_1 \frac{\varepsilon}{K} P - C_2 \frac{\varepsilon^2}{K} + C_3 \frac{\varepsilon}{K} G \tag{5}$$

Here, P is the production of turbulent energy, and G is the dissipation rate of turbulent energy. The definitions of parameters and model constants in the above equations are described in the paper of Kim and Kim [7].

For the collection efficiency of particles, a droplet motion equation is solved. The motion equation of the trajectory of a particle is

$$\frac{d\vec{v}_p}{dt} = -\frac{18\eta_f}{\rho_p \phi^2} C_D \frac{\mathrm{Re}}{24}\left(\vec{v}_p - \vec{v}_f\right) + g \tag{6}$$

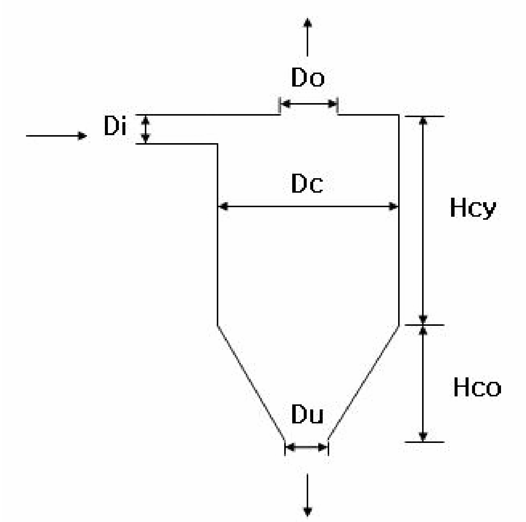

Figure 1. Schematic diagram of a hydrocyclone geometry. Dc-Cylinder diameter, Di-Inflow diameter, Do-Overflow diameter, Du-Underflow diameter, Hcy-Cylinder height, Hco-Cone height.

Here, η_f is the dynamic viscosity of a fluid, $\vec{v}_p$ is the velocity of a particle, $\vec{v}_f$ is the velocity for a fluid, ϕ is the diameter of a particle, g is the acceleration due to gravity, Di is the diameter of the inlet, Do is the diameter of the upper outlet, Du is the diameter of the bottom outlet, Dc is the diameter of the cylinder, Hcy is the height above the cone section and Hco is the height of the cone section of the cylinder.

The Reynolds number is defined as follows:

$$\mathrm{Re} = \frac{\rho_f \phi \left| \vec{v}_p - \vec{v}_f \right|}{\eta_f}$$

with following Clift et al. [2]

$$C_D = \frac{24}{\mathrm{Re}_p}\left(1 + 0.15\,\mathrm{Re}_p^{0.687}\right).$$

A finite volume method is applied to flow prediction. The detailed descriptions of a numerical method are described in the paper [7].

Results and discussion

To test the correctness of the solution, it was compared with the experimental solution [3]. Figure 2 shows comparative results of velocity profiles. In this case the vortex finder is installed at the overflow section. At each section, the velocity distribution obtained in the study agrees well with experimental results. It can be seen that high velocities are encountered near the air-core. In the centre of the cyclone, the fluid exits to the vortex finder. Near the outer wall of the cyclone, the negative velocity distribution is established. This means that the flow at the outer wall of the cyclone go down to the downflow exit. Figure 3 displays the average velocity and pressure profiles with varying inlet velocity conditions. Though not shown in figure 3, the velocity flow at different inlet velocity profiles shows similar swirling patterns. As the inlet velocity increase, the velocity profile of internal flow of a hydrocyclone increase linearly. The flow phenomena of a cyclone show very complex flow patterns of vortex and turbulent flow. However, the fluid is well satisfied the conservation of mass, because the fluid is incompressible. Overall pressure distribution increases almost linearly as the inlet velocity increases.

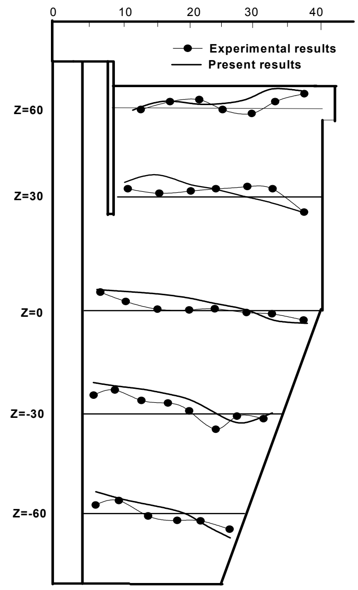

Figure 2. Comparative results of velocity profiles.

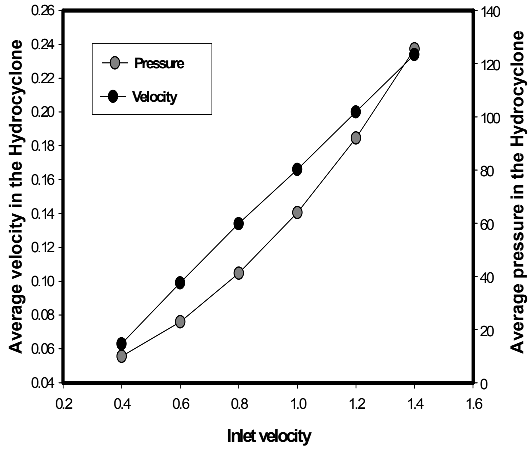

Figure 3. Average velocity and pressure profiles in a hydrocyclone.

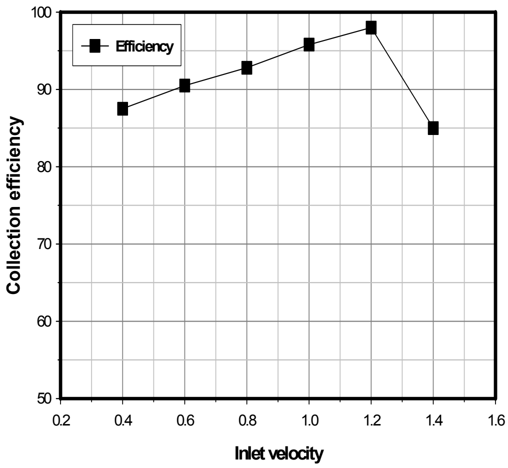

Figure 4. Collection efficiencies with varying of inlet velocities.

Figure 4 shows the collection efficiencies with varying inlet velocities. For this calculation, the droplet motion equation is used, and we assume that a particle is uncoupled with fluid properties. This means the flow governing equations are first solved. Based on those results, the motion equation is solved. The definition of particle efficiency is shown in the paper [1]. The collection efficiency initially increases as the inlet velocity increases to the inlet velocity of 1.2 m/s. After 1.2 m/s of inlet velocity, the efficiency decreases. At 0.4 m/s of small inlet velocity, it is expected the increase of the efficiency by gravitational sedimentation. However, in the study, the efficiency is low. The efficiency of a hydrocyclone is related to a geometry which effects flow mechanism within a cyclone. Figure 5 shows the mass flow rate and efficiency with varying underflow diameters at 1.2 m/s of inlet velocity which shows the best result in Fig. 4. When the underflow diameter increases the efficiency increases. However, after 50 mm, the efficiency approaches a constant value.

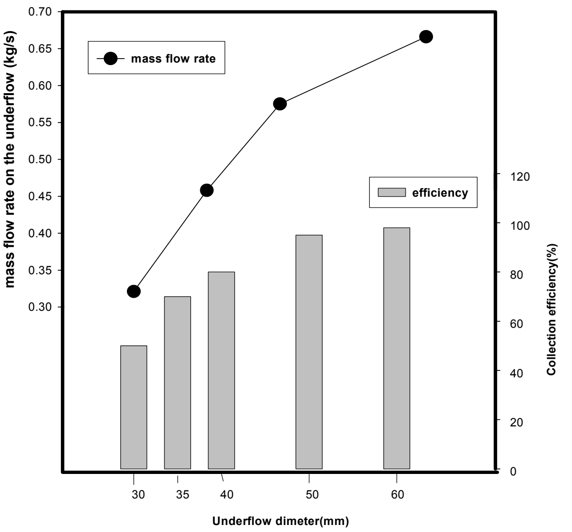

Figure 5. Mass flow rate and collection efficiency.

Figure 6 displays the collection efficiency at different particle sizes. The maximum efficiency occurs at 2.5 mm. For large particle sizes (1.6, 2.0, 2.2 mm) the effect of gravitational sedimentation will increase. It can be seen from figure 6 that the collection increases up to the particle sizes of 2 mm diameter. .

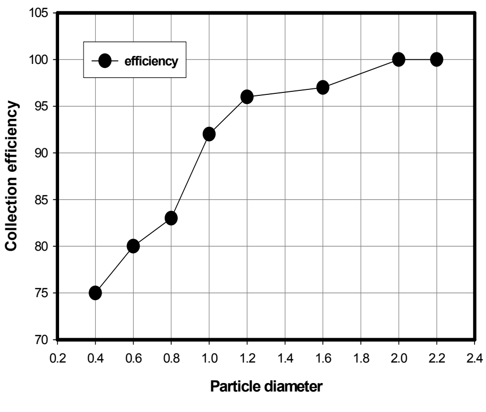

Figure 6. Collection efficiency at different particle.

Conclusions

In a fish-breeding industry, effluent water is disposed by gravity sedimentation. Thus, a large settling tank and a lot of water are needed to purify effluent water. Instead of the typical method a hydrocylone is tested to discharged water which contains a lot of feeding sediments. We investigated design parameters for good performance of a hydrocyclone. The results can be used to construct a vortex cyclone which is expected to be a system capable of protecting environment maintaining a stable efficiency.

References

[1] Berlemont, A., Grancher, M.S. & Gouesbet, G. Heat and Mass Transfer Coupling between Vaporizing Droplets and Turbulence using a Lagrangian Approach, *Int. J. Heat Mass Transfer*, **38**, 1995, 3023-3034.

[2] Clift, R. Grace J.R. & Weber, M.E., Bubbles, *Drops and Particles*, Academic Press, 1987.

[3] Dai, G., Li J.M. & Chen, W.M., Numerical Prediction of the Liquid Flow within a Hydrocyclone, *Chem. Eng. J.*, **74**, 1999, 217-223.

[4] Dirgo, J., & Leith, D., Cyclone Collection Efficiency: Comparison of Experimental Results with Theoretical Predictions, *Aerosol Sci. Technol.*, **4**, 1985, 401-410.

[5] Frachon, M. & Chlliers J.J., A General Model for Hydrocyclone Partition Curves, *Chem. Eng. J.*, **73**, 1999, 53-59.

[6] Griffiths, W.D., & Boysan, F., Computational Fluid Dynamics and Empirical Modelling of the Performance of a Number of Cyclone Samplers, *J. Aerosol Sci.*, **27**, 1996, 281-304.

[7] Kim, H. & Kim, E., Characheristics of an Entrainment into the Turbulent buoyant Jet in a Cross Flow, *KSME J.*, **23**, 1999, 342-351.

[8] Madhumita, B.R., Improving the Removal Efficiency of Industrial-scale Cyclones for Particles Smaller than five Micrometre, *Int. J. Miner. Process.*, **53**, 1998, 39-47.

[9] Mothes, R., & Loffer, F., Prediction of Particle Removal in Cyclone Separators, *Int. Chem. Eng.*, **28**, 231-240.