I. Introduction

Aquaculture’s product including fish is an important food source. Aquaculture becomes more popular nowadays and seems to be the only way to solve the problem associated with the depletion of the world wild fish stocks [1]. The aquaculture industry is the fastest growing food production where the production increases over the years [2]–[4]. Aquaculture’s product can be a significant animal protein sources for the poor as reported by the study conducted by Garlock et al. [5] who found that the increase in the aquatic food consumption by the poor is related with the increase in aquaculture production. Aquaculture can also be a solution for micronutrient deficiency which often occur in developing countries [6]. Indonesia with a relatively large population is also need to expand the aquaculture sector to ensure the food security. This is reflected in the quite high target for expanding the aquaculture sector up to 2030 set by Indonesian government [3].

One of the efforts to expand the aquaculture can be the development of aquaculture in various scales including in the household or small community scale in addition to industrial scale. Fig. 1 shows an example of an aquaculture or aquaponic applied in a small community close to a river bank in Indonesia. The influent water is obtained from a small waste water processing system responsible to process waste water from several nearby restaurants. The concept of the aquaponic system applied in this place is not only to utilize the remaining nutrients for vegetable and fish feed but also as additional filtration process for the waste water prior releasing it to the river. Fig. 1a shows the location of the aquaculture which is close to a river bank. Fig. 1b-d shows the fish culture tank, the fish inside the tank and the vegetable grows in the top of the tank, respectively.

The rapid development of aquaculture cannot be separated from the application of science and technologies in this sector as explained in the review article of Yue and Shen in [1]. One of the important technologies is in the design of the fluid flow condition inside the aquaculture tank. Several studies related with the fluid flow conditions inside the tanks can be found in [7]–[11]. To provide

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**ARTICLE INFO**

**ABSTRACT**

Aquaculture is an important sector for providing a food source. Technology may help the development of aquaculture including in the design of the fluid flow condition beneficial for aquaculture tank design and its operational parameters. In this study, the use of Computational Fluid Dynamics (CFD) to provide local fluid flow information was demonstrated. In the first case, the fluid flow condition generated by two different inlet orientations, namely the straight inlet and the angled inlet was investigated. The significant difference in the fluid flow pattern was observed by the help of the velocity streamlines. In the second case, the transient CFD simulation was used to determine the transient temperature distribution for the two different inlet orientations. The result also shows the significant different in the distribution which closely related to the generated fluid flow by both inlet orientations.
detail local information regarding the fluid flow inside the tank, computational fluid dynamics (CFD) can be used. This information might be useful to optimize the design of the fish culture tanks as well as the operating conditions. Therefore, in this study, the ability of CFD to provide several local information such as the velocity streamlines and also the transient distribution of temperatures for a cube-shaped tank is demonstrated. The comparison is made between two different inlet orientations, namely a straight inlet and an angled inlet.

Fig. 1. A small scale aquaculture or aquaponic system applied in a small community close to a river bank: (a) the location, (b) small-scale fish culture tank, (c) fish inside the tank and (d) vegetable grows in the aquaponic system.

II. Method

For CFD simulation, a cube-shaped tank as shown in Fig. 3 was used for the computational domain. The length of each side is 100 cm. The inlet and outlet are located at the distance of 10 cm below the top and bottom of the tank, respectively. The diameter of inlet and outlet pipe is 5 cm. For the straight
inlet, the inlet pipe is oriented perpendicular to the wall of the tank while for the angled inlet a 45° angle is applied.

Fig. 2. The computational domain of the tank for CFD simulations.

All CFD simulations were carried out as single-phase simulation. The fluid is water. The continuity and momentum equations which are required to be solved for all computational cells [12]:

\[
\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \, \mathbf{U}) = 0
\]  

(1)

\[
\frac{\partial (\rho \, \mathbf{U})}{\partial t} + \nabla \cdot (\rho \, \mathbf{U} \times \mathbf{U}) = -\nabla p + \nabla \cdot \mathbf{\tau} + S_M
\]

(2)

where \( \rho \) represents the water density, \( \mathbf{U} \) is the velocity vector, \( t \) is the time, \( p \) is the pressure, \( \mathbf{\tau} \) is the stress tensor and \( S_M \) is the momentum source [12]. For the second case where the heat transfer is involved, the thermal energy equation is also need to be solved [12]:

\[
\frac{\partial (\rho \, h)}{\partial t} + \nabla \cdot (\rho \, \mathbf{U} \, h) = \nabla \cdot (\lambda \, \nabla T) + \nabla \cdot \mathbf{\tau} + \nabla \cdot \mathbf{U} + S_E
\]

(3)

The CFD simulation for the first case was performed under the steady-state and adiabatic mode. The CFD simulation for the second case was carried out under transient mode. The velocity of 1 m/s was defined as the inlet boundary condition both for the straight inlet and the angled inlet. For the outlet, a pressure boundary condition was used. The no-slip wall condition was used for other parts.
For the turbulence model, the \( k-\omega \)-based shear stress transport (SST) model proposed by [13] was used. ANSYS CFX Student Edition software was used to conduct all the CFD simulations in this study.

III. Results and Discussion

CFD can be used to predict the influence of fish culture tank geometry and also inlet – outlet configuration on the generated flow pattern. This information can be used to optimize the tank design or to modify the existing tank in order to improve the flow condition. Once the information regarding the preferable flow condition for fish culture is obtained (e.g., from an experiment), a fish culture tank designer can direct his design so that the targeted flow condition can be reached. For each change made on the design, the designer can evaluate the generated flow condition by using CFD before the manufacturing process. This may help in reducing the cost since trial and error can be made in the designing process and simulated using CFD instead of conducting it in the physical experiment.

Fig. 3. Velocity streamlines inside the tank with (a) a straight inlet (3D view), (b) a straight inlet (top view), (c) an angled inlet (3D view), (d) an angled inlet (top view).

A simple example of how CFD can be used to investigate the influence of the inlet configuration is presented in Fig. 3. That figure shows the velocity streamlines of cube-shaped tank for two different inlet orientations. It is demonstrated that by using CFD we can simulate the flow condition and found the significant difference between the flow condition obtained in the tank with a straight inlet (inlet perpendicular to the tank surface) and one with an angled inlet. In the case of straight inlet, the injected fluid flows straight to the opposite wall and then generates a relatively symmetric swirl flow in the both sides of the main stream (see Fig. 3 b). Differently, in the case of an angled inlet, the injected fluid generates rotating flow in the circumference of the tank with the lower velocity close to the center. Which one of this flow pattern is preferable for fish culture should be obtained from an
experiment in a real fish culture tank. The example of important factors needs to be considered associated with this flow pattern can be the distribution of the remaining fish feed or the fish feces. If a more detailed information on these distributions is required, two-phase CFD simulation then can be performed.

Fig. 4. Transient temperature distributions on several planes inside the tank with a straight inlet at: (a) 5 s, (b) 60 s, (c) 150 s and with an angled inlet at: (d) 5 s, (e) 60 s and (f) 150 s.

In the case that the fish culture is highly sensitive on the temperature, or there is a requirement to control the temperature in a relatively narrow range then CFD can also be used to determine the temperature distribution in the tank. Fig. 4 shows transient temperature distributions for a straight inlet and an angled inlet for 5s, 60s and 150s. The temperature distribution is shown for three different cross-sectional planes with the vertical distance of 10 mm, 50 mm and 90 mm. The temperature distribution at 5s (see Figs. 4a and 4d) shows different distribution obtained for the tank with a straight inlet (Fig. 4a) and an angled inlet (Fig. 4d). In this early injection of the hotter water, only the top plane which is affected. The distribution closely related to the flow pattern generated by those two different inlet orientations. The higher temperature region for the tank with a straight inlet is located in the region close to the top center of the tank while for an angled inlet is located in the
region close to the top side wall of the tank. The temperature of the water inside tank increases gradually along the time. Fig. 4b and 4e show the temperature distribution at 60s for a straight inlet and an angled inlet case, respectively. All measurement planes are now affected by the injection of the hotter water. The significant difference on the temperature distribution still can be observed between the two cases. For an angled inlet case, the minimum temperature is found in the central region for all planes. This is highly associated with a rotating flow generated due to the angled inlet. In contrast, this phenomenon is not found in the case of the straight inlet. A similar trend still can be observed at 150s as can be seen in Fig. 4c and 4f. Although the temperature is higher at this time, a minimum temperature region still can be found in the central region of the angled inlet case. This result demonstrates the ability of CFD to provide the transient local information which may be useful in designing or optimizing the fish culture tank as well as its operating conditions.

IV. Conclusion

CFD simulations were conducted in this study to demonstrate the its ability to provide local flow information. In the first simulation case, the flow condition generated by two different inlet orientations of the tank was compared from the CFD result. The velocity streamlines show significant difference in the flow pattern generated for those two cases. In the second simulation case, CFD was used to present the transient distribution of temperature obtained by the injection of the hotter water to the tank which already filled with the colder water. The transient distribution plotted on some cross-sectional planes shows different distribution between the case of the straight inlet and the angled inlet. The transient distribution of the temperature obtained for both cases was closely related with the flow condition generated by both inlet orientations.

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References

[1] K. Yue and Y. Shen, “An overview of disruptive technologies for aquaculture,” *Aquac. Fish.*, vol. 7, no. 2, pp. 111–120, Mar. 2022, doi: 10.1016/j.aaf.2021.04.009.

[2] T. Gjedrem, N. Robinson, and M. Rye, “The importance of selective breeding in aquaculture to meet future demands for animal protein: A review,” *Aquaculture*, vol. 350–353, pp. 117–129, Jun. 2012, doi: 10.1016/j.aquaculture.2012.04.008.

[3] P. J. G. Henriksson et al., “Indonesian aquaculture futures – Evaluating environmental and socioeconomic potentials and limitations,” *J. Clean. Prod.*, vol. 162, pp. 1482–1490, Sep. 2017, doi: 10.1016/j.jclepro.2017.06.133.

[4] N. Tran et al., “Indonesian aquaculture futures: An analysis of fish supply and demand in Indonesia to 2030 and role of aquaculture using the AsiaFish model,” *Mar. Policy*, vol. 79, pp. 25–32, May 2017, doi: 10.1016/j.marpol.2017.02.002.

[5] T. Garlock et al., “Aquaculture: The missing contributor in the food security agenda,” *Glob. Food Secur.*, vol. 32, p. 100620, Mar. 2022, doi: 10.1016/j.gfs.2022.100620.

[6] A. Shepon et al., “Exploring sustainable aquaculture development using a nutrition-sensitive approach,” *Glob. Environ. Change*, vol. 69, p. 102285, Jul. 2021, doi: 10.1016/j.gloenvcha.2021.102285.

[7] J. Zhang, G. Jia, M. Wang, S. Cao, and S. G. Mkumbuzi, “Hydrodynamics of recirculating aquaculture tanks with different spatial utilization,” *Aquac. Eng.*, vol. 96, p. 102217, Feb. 2022, doi: 10.1016/j.aquaeng.2021.102217.

[8] S. T. Summerfelt, J. W. Davidson, T. B. Waldrop, S. M. Tsukuda, and J. Bebak-Williams, “A partial-reuse system for coldwater aquaculture,” *Aquac. Eng.*, vol. 31, no. 3, pp. 157–181, Oct. 2004, doi: 10.1016/j.aquaeng.2004.03.005.
[9] M. R. Rasmussen and E. McLean, “Comparison of two different methods for evaluating the hydrodynamic performance of an industrial-scale fish-rearing unit,” *Aquaculture*, vol. 242, no. 1, pp. 397–416, Dec. 2004, doi: 10.1016/j.aquaculture.2004.08.045.

[10] P. Cornejo, H. H. Sepúlveda, M. H. Gutiérrez, and G. Olivares, “Numerical studies on the hydrodynamic effects of a salmon farm in an idealized environment,” *Aquaculture*, vol. 430, pp. 195–206, Jun. 2014, doi: 10.1016/j.aquaculture.2014.04.015.

[11] J. M. R. Gorle, B. F. Terjesen, and S. T. Summerfelt, “Hydrodynamics of octagonal culture tanks with Cornell-type dual-drain system,” *Comput. Electron. Agric.*, vol. 151, pp. 354–364, Aug. 2018, doi: 10.1016/j.compag.2018.06.012.

[12] ANSYS, “ANSYS CFX-Solver Theory Guide, Release 19.2.” 2019.

[13] F. R. Menter, “Two-equation eddy-viscosity turbulence models for engineering applications,” *AIAA J.*, vol. 32, no. 8, pp. 1598–1605, Aug. 1994, doi: 10.2514/3.12149.