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Transient Numerical Study to Determine the Effect of Inlet Angle Variation on Flow Conditions inside a Circular Aquaculture Tank

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ABSTRACT

Seeing how great the contribution and potential of the aquaculture sector to the fulfillment of food for the people of Indonesia, the development of aquaculture including the Recirculating Aquaculture System (RAS) is very important to be carried out intensively. An important aspect that should be considered for the development of RAS is maintaining water quality as the main medium of cultivation. Optimization of the aquaculture tank is an effort that can be conducted to achieve this goal. A transient numerical study to determine the effect of inlet angle variation on flow conditions inside a circular aquaculture tank was conducted to assess the optimum geometry for the application. Single phase CFD simulations using the k-ω SST turbulent model were carried out to evaluate the effect of inlet nozzle angle variations. Three angle variations 0°, 45°, and 90° were selected and the resultant fluid flow conditions were analyzed. From the CFD results, it can be known that the optimum condition for the circular aquaculture tank is achieved for the angle 0° among the tested angle in this present study.

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I. Introduction

Indonesia's food sovereignty is one of the goals that has always been echoed by the Indonesian government from year to year in an effort to maintain economic and food security. The population in Indonesia is increasing rapidly. In 2030, it is predicted that the population in Indonesia will be 294.1 million, while in 2045 it will be 318.9 million [1]. The increase in Indonesia's population is in line with the increasing demand for energy and food. Indonesia as a maritime country with the largest archipelago in the world with a water area of 3,257,483 km^2 and has around 17,499 islands, has several resource sectors that can still be maximized to fulfill community food security including marine and fisheries [2]. Those resources are prospective sectors to be developed given the potential for a large amount of biodiversity in Indonesia. Indonesia's marine and fisheries resources are the second largest in the world after China [3]. In a global perspective, the need for fishery products is projected to be increase from 67 million tons in 2012 to 140 million tons in 2050 [4]. This represents a total of 14 percent of the animal protein needs required by the world's human population [4].

Although the culture of eating fish in Indonesia is still considered low compared to other countries that have potential fishery resources below Indonesia, such as Malaysia and Myanmar, Indonesian people's interest in protein derived from aquatic animals continues to increase from year to year [5]. It was recorded that fish consumption in 2014 amounted to 38.14 kg / capita, in 2020 there was an increase to 56 kg / capita, or an increase of 3.47% from 2019 [6]. Public interest in the consumption of aquatic animals encourages an increase in the production of fishery products. Fisheries production in Indonesia is categorized into two parts, namely capture fisheries and aquaculture. The increase in fisheries production occurred from both capture fisheries and aquaculture, although in the capture fisheries sector the increase was very small and tended to stagnate. Based on data from the Food and Agriculture Organization (FAO), fisheries production from capture in the wild is relatively stagnant from 1990 to 2030 at 90 million tons per year [7]. Meanwhile, it is predicted that aquaculture production will more than double the production of capture fisheries by 2030 [7].

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Seeing how much the aquaculture sector contributes and has the potential to fulfill the food needs of the Indonesian people, the development of aquaculture is very important to be carried out intensively. The direction of aquaculture development in Indonesia is the application of fisheries infrastructure technology, and creating a space-intensive aquaculture model to maximize total fish production, and sustainability. The development of aquaculture in Indonesia will continue to grow in line with the creation of sustainable aquaculture, fisheries that pay attention to their impact on the surrounding environment. One of the technological applications that is being widely developed and applied in order to achieve the goal of sustainable aquaculture with the carrying capacity to minimize its impact on the environment is the Recirculating Aquaculture System (RAS) fishery method [8]. The RAS system minimizes water usage in aquaculture systems where 90-99% of the water can be reused if the water recirculation system is well run [9]. The RAS system makes it easy for farmers to control environmental conditions and water quality according to the type of fish available, this is done to improve the quality of life of fish and away from disease [9].

The main aspect that must be considered for the development of RAS is maintaining water quality as the main medium of cultivation. The water entering the depth of an aquaculture system must be clear and free from unnecessary matters [8]. Particles that cause turbidity should be removed by filtration and then precipitated [8]. Water quality is an important requirement that can have a direct impact on the survival, fish physiology, growth rate, and feed efficiency [10]. A good environment is required to produce high-quality fishery products. The RAS system has several components in it, one of the components to support the level of water quality is the aquaculture tank which is the main place where fish live and grow. The aquaculture tank must be designed in such a way that it becomes a good place for fish [11]. One of the things that is considered in the development of aquaculture tanks is by looking at the level of self-cleaning of the tank, how the flow pattern occurs in the tank that is suitable for breeding fish, and the speed of fluid flow in the tank [12]. Since the design of aquaculture tank is important, the hydrodynamics inside the tank was numerically investigated in this work. This study examines the effect of nozzle angle variation at the inlet of a circular tank on the flow conditions inside the tank.

II. Method

CFD simulations were carried out using ANSYS Fluent software to solve governing equations under transient mode. The continuity and momentum and energy equations solved in the simulation are as follows, respectively [13]:

$$\frac{\partial \rho}{\partial t} + \nabla . (\rho \vec{v}) = 0 \tag{1}$$

$$\frac{\partial}{\partial t}(\rho \vec{v}) + \nabla . (\rho \vec{v}\, \vec{v}) = -\nabla \mathrm{p} + \nabla . (\bar{\tau}) + \rho \vec{g} + \vec{F} \tag{2}$$

The CFD simulations were conducted for circular tank based on the experimental work of [14]. The Computer Aided Drawing (CAD) for the tank's geometry of the present study is presented in **Figure 1**.

The tank geometry used in this study is a tank with a circular geometry with a diameter of 7 meters. The type of tank used is the center drain tank (CDT) type. CDT is a type of aquaculture tank with a drain or outlet configuration centered in the middle at the bottom of the tank. At the bottom of the tank, a certain slope or conical is made with the intention of producing a self-cleaning effect on the aquaculture tank. The slope of the tank is identical to that in [14] for research validation needs. The tank geometry has a horizontal inlet type located near the tank wall. The inlet has 6 nozzles with identical diameters of 0.04 m each. For the initial condition, the nozzle angle forms an angle of 0° from the normal axis in line with the tank geometry, then for angle variations it is set at 45° and 90° to the normal axis of the tank. The outlet is a pipe with a diameter of 0.2 mm that extends from the drain and then upwards parallel to the aquaculture tank wall. In this study, water fluid with a velocity of 1.34 m/s was used in each simulation performed.

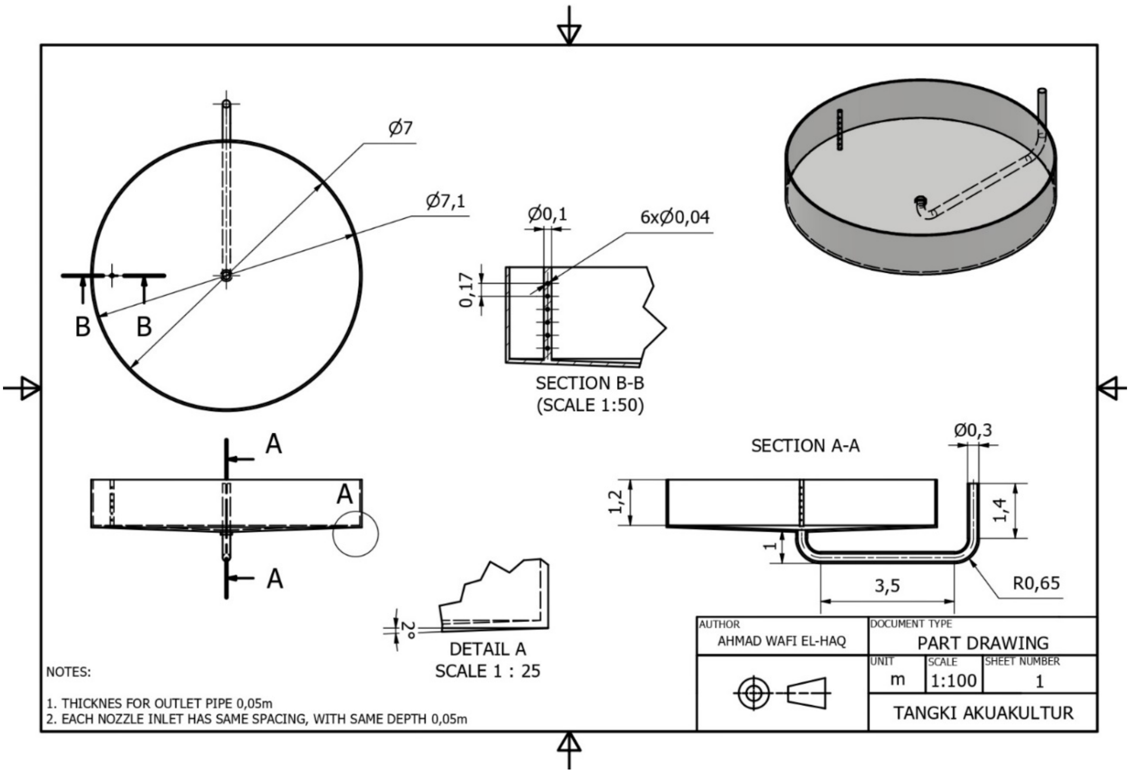

Fig. 1. The Computer Aided Drawing (CAD) for the tank's geometry of the present study (based on [14])

For validation purposes, velocity in several points from CFD results was compared to the experimental data of [14]. The position of those points where the velocity was measured on the tank can be seen in **Figure 2**. The water flow in the tank flows clockwise with respect to the cartesian coordinates. The measurement points are arranged in three measurement zones. Points Ai (i = 1,2,3) and Bi (i = 1,2,3) are located 0.5 m from the wall. Points A1 and B1 have a depth of 0.2 m from the tank surface. Points A2 and B2 are 0.35 m deep, while points A3 and B3 are 0.5 m deep. Point Ci (i = 1,2,3) is directly above the tank drain, measured from the drain. Point C1 has a depth of 0.8 m from the drain, point C2 has a height of 0.95 m and 1.1 m for point C3.

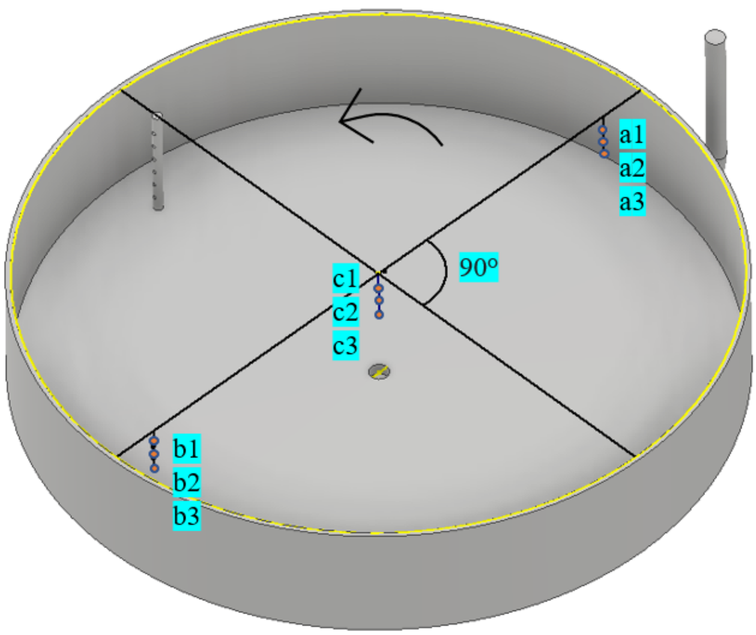

Fig. 2. The location of the points of the velocity measurement for the validation purposes [14].

III. Results and Discussion

The comparison between the velocities obtained from the CFD simulation and the experiment is presented in **Figure 3**. In general, the results of CFD are in agreement with the experiment. Next, the influence of inlet angle from the CFD results can be analyzed.

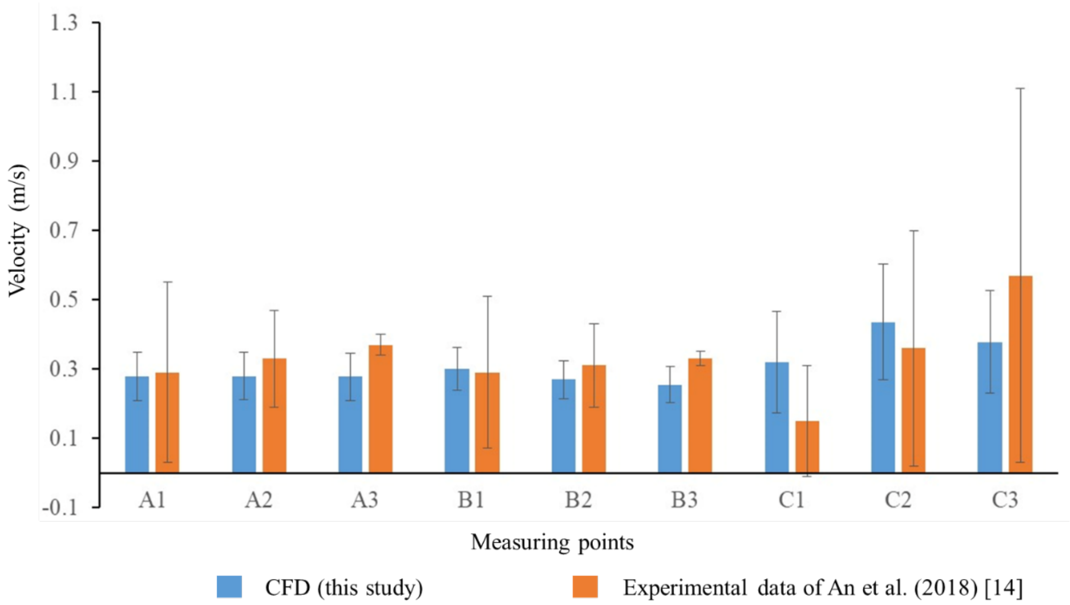

Fig. 3. Comparison between velocity obtained in this CFD study and the experiment of An et al. [14].

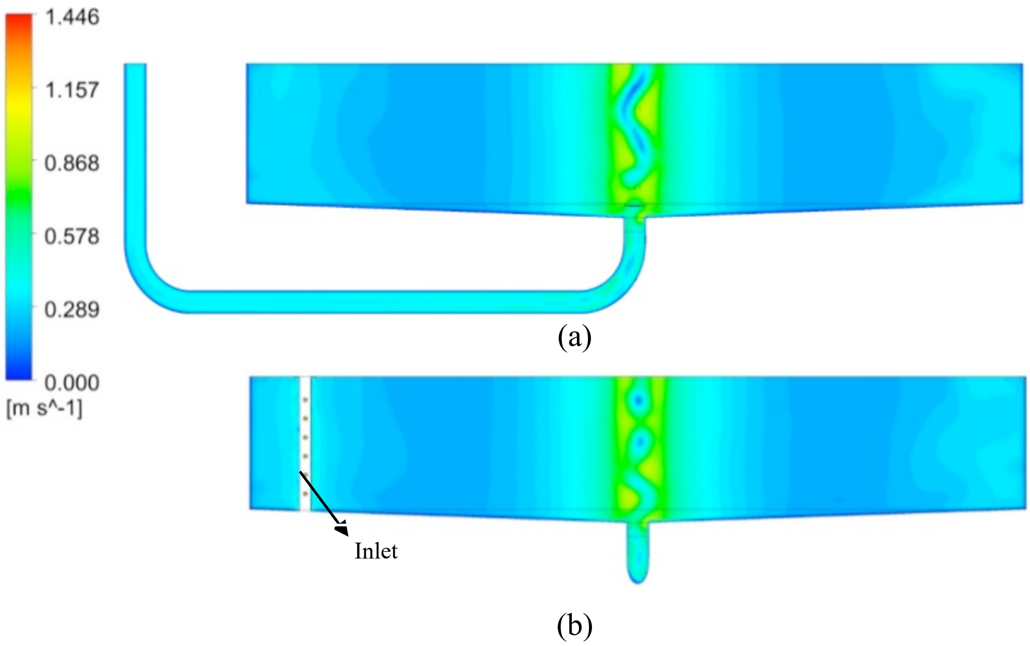

Fig. 4. Velocity contours on the tank with 0° nozzle angle geometry: (a) XY plane and (b) YZ plane.

The optimum tank condition is when the flow velocity can be distributed throughout the tank body so that the dissolved oxygen can be evenly distributed in the tank [16]. The effect of flow velocity can create good mixing in the inflow [17]. Furthermore, the flow conditions and geometry at the inlet can affect the ability of a tank to remove unneeded substances such as food waste, dirt, and other solids or commonly called the self-cleaning ability of the tank. To see the effect of the inlet nozzle angle on the velocity distribution in the tank the velocity contours are presented in **Figures 4-6**. Those figures are plotted at the same flowtime of 30 thousand seconds when it has shown steady state conditions in the fluid flow in the circular aquaculture tank. The maximum velocity is located at the inlet of the aquaculture tank equal to the inflow rate of the fluid into the tank while the minimum velocity is located on the tank wall either on the left right or the bottom of the tank. The increase in fluid flow rate can be seen in the fluid volume section perpendicular to the tank drain position. At the center of the tank there is an increase in fluid velocity due to the drain located at the base of the tank center. It can be concluded that the flow at 0° is the most evenly distributed among the nozzle angles tested in this study.

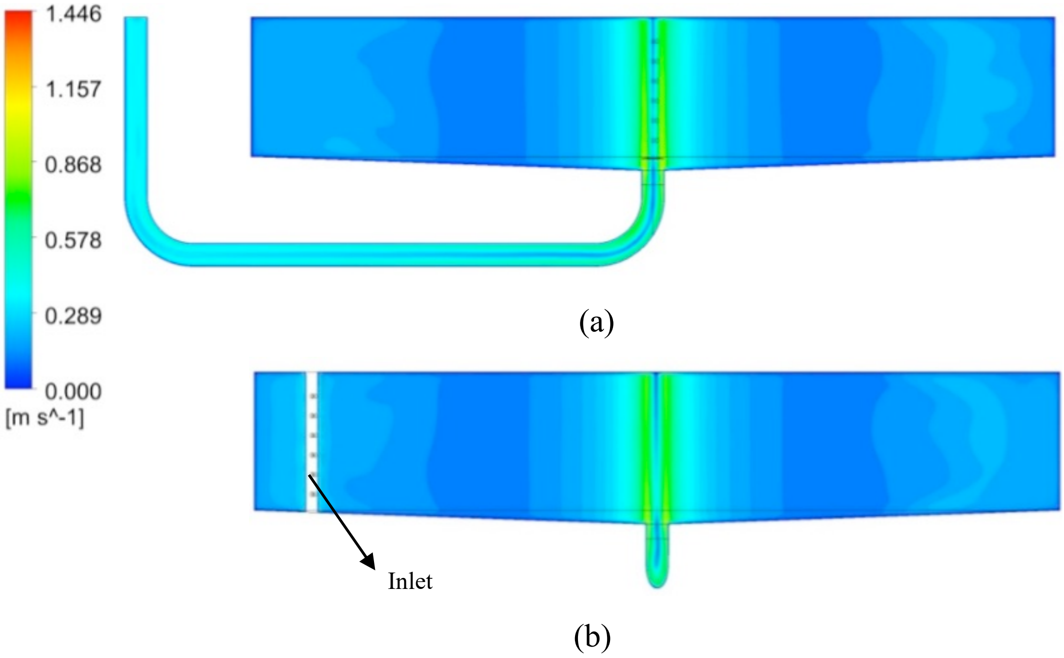

Fig. 5. Velocity contours on the tank with 45° nozzle angle geometry: (a) XY plane and (b) YZ plane.

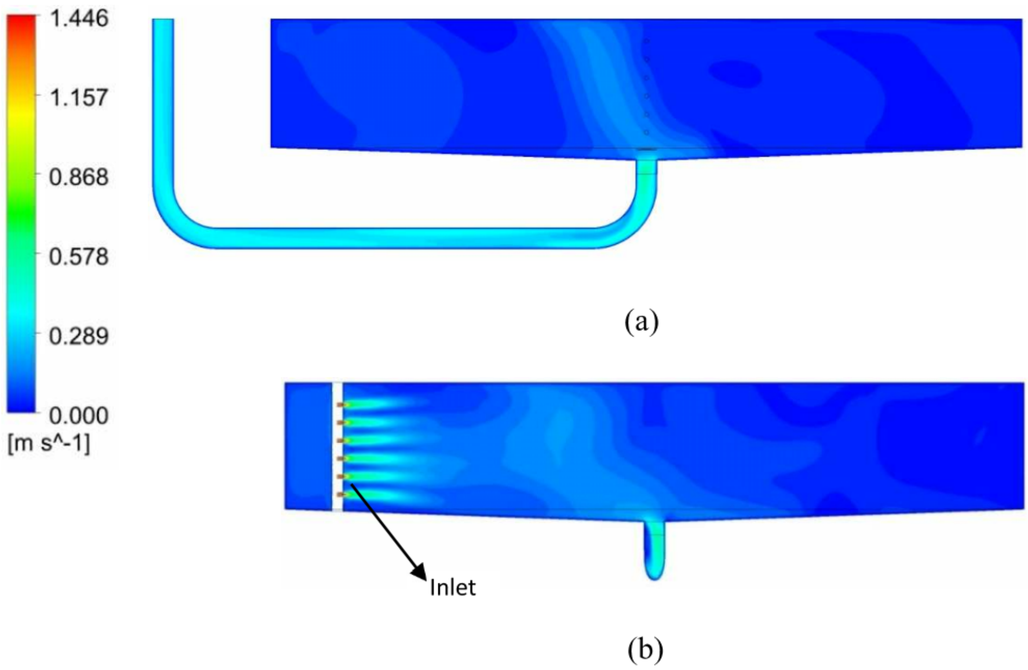

Fig. 6. Velocity contours on the tank with 90° nozzle angle geometry: (a) XY plane and (b) YZ plane.

IV. Conclusion

Flow simulations in aquaculture tanks have been conducted using computational fluid dynamics. CFD is used to predict the flow patterns that occur in aquaculture tanks. The information generated in this simulation can be used to optimize for better flow patterns for aquaculture, prior to the manufacturing process. The simulation was performed using the k-ω SST turbulence model with curvature correction enabled to illustrate the effect of the vortex caused by the fluid entering through the inlet. The different geometry shapes at the inlet nozzle affect the flow velocity contours. Geometry with a nozzle angle of 0° shows the best results. The velocity distribution in the 0° geometry is more evenly distributed in comparison to the case of 45° and 90°. Geometry with a 90° nozzle angle shows poor velocity distribution, so it is not well applied to tanks with circular geometry.

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