February 2013. Vol. 2, No.2 ISSN 2305-8269

International Journal of Engineering and Applied Sciences

www.eaas-journal.org

THE DESIGN OF A CULTURE TANK IN AN AUTOMATED RECIRCULATING AQUACULTURE SYSTEM

Jer-Vui lee[1], Joo-Ling Loo, Yea-DatChuah, Pek-Yee Tang, Yong-Chai Tan ,Chen-How Wong

Department of Mechatronics and Biomedical Engineering, Faculty of Engineering and Science, UniversitiTunku Abdul Rahman, Kuala Lumpur, Malaysia.

leejv@utar.edu.my[1]

Abstract

This project aims to develop a closed-loop automated recirculating aquaculture system (RAS) with low maintenance and emphasizingon 3R (reuse, reduce and recycle) concept in water usage. Conical shaped tank with an inclined angle at 20°is used as the culture tank. The drain is located at the bottom of the tank and the solid wastes can easily be removed automatically. Computational Fluid Dynamics (CFD) was used to study the fluid flows problems in the culture tank. Simulations were carried out to compare flow inlet structures which were tangential flow pattern and normal flow pattern. Normal inlet flow is poor in self-cleaning sinceits power is reduced. Tangential flow inlet is better in term of self-cleaning and its optimal speed is 20to 30 m/s.

Keywords: Culture Tank, Geometry Design and Recirculating Aquaculture System

1. Introduction

Recirculating aquaculture system (RAS) provides a unique way to farm fish under conditions instead of the conventional method. RAS reuses water over and over, cleans the waste from the water and provides oxygen to culture tanks. RASs have been investigated by many authors [1-8]. Numerous studies of recirculation system have been investigated at overall system performance and on specific dynamics of individual processes and system component design during this past ten years.

2. Related Work

Fish tank is an important component in RAS and it provides the fish culturing environment. There are many styles of fish tanks that come in a variety of sizes and shapes (e.g. circular, rectangular, square and oval) [9]. Circular and oval tanks with central drain are easier to be cleaned with water circulation compared with the rectangular tank. The rectangular tanks are usually built with incline floor to facilitate cleaning and circulation [10].The bases with white or lighter colours assist in fish husbandry and management. In the other hand, the colour of tank should be dark or dull to minimize the stress effects[9]. The sides of tanks can be installed with a small window for useful observing stock.

Tanks base is commonly flat to slightly sloping (less than 15 degrees) to allow workers to work safely inside the tanks. The design of tanks should include the functionality of self-cleaning. The water flow characteristics of the tank design allow the concentration of wastes or debris toward outlet points. Circular tanks are generally preferred because it is easy to be managed and its ability of self-cleaning. It produces uniform water flow patterns which are required to concentrate and remove solid. In addition, it provides relatively uniform water quality as well as its culture environment.

Several authors have carried out the research on the circular aquaculture tank [11-14]. Joan Ocaet al proposed model which estimates the distribution of velocities by determining the angular momentum per unit mass next to the tank wall and around the central axis [12]. The velocity profiles in a diametrical axis of a circular aquaculture tank with a tangential water entry and a bottom central outlet has been analyzed by trying different flow rates, water inlet velocities and water heights.Steven et al developed and evaluated several types ofrelatively inexpensive, portable, and efficient fish handling equipment to reduce the labor requirement for grading and harvesting fish from large circular culture tanks [13]. Andrew et al has designed and constructed a bespoke automated mechanical cleaning device to assist the removal of biosolids [14]. The study has proven to clear unwanted material from the bottom of tanks at a significantly rate (P< 0.0005) faster than from a tank without the device.

To establish self-cleaning, the water column must be in constant rotation within the tank. Its velocity in the culture tank should be uniform from the tank wall to the centre and from the surface to the bottom [11]. More importantly, it should be swift enough to make the self-cleaning effect of the tank. However, it should not be faster than that required to the daily exercise of the fish. Properly designed inlet intake-outlet provisions also contribute to self-cleaning characteristics.The only disadvantage of the circular tanks required more space to house them compared to the square, rectangular or octagonal tanks [9].

3. Methodology

3.1 Overall System Architecture

Tanks used for intensive culture of fish are of various shape and flow pattern [11]. The design considerations include space utilization, water quality maintenance, cost of production and fish management. Geometry, flow patterns, fluid velocity are particularly important design considerations. The overall system architecture is shown in Figure 1. It consists of tank, piping, valve, filtration and pump. The site layout of the project is shown in Figure 2.

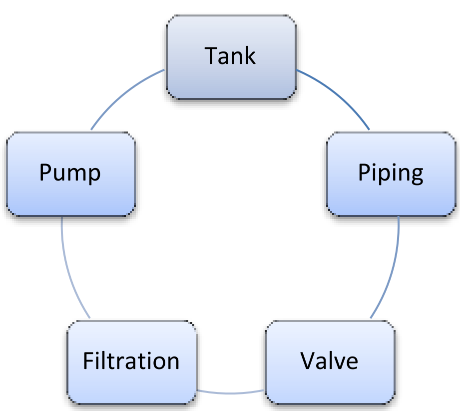

Figure 1: Site Layout

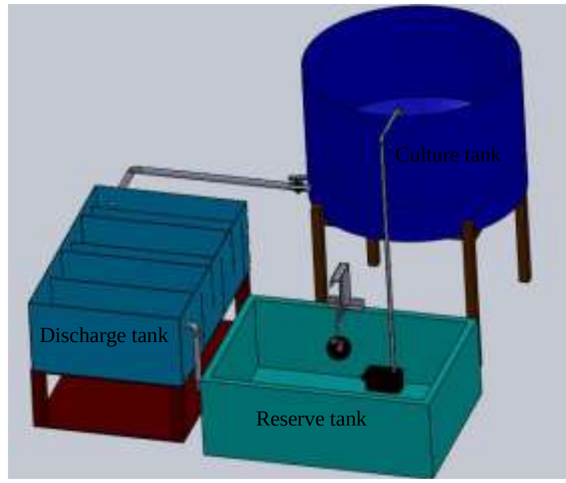

Figure 2: Site Layout

3.2 Tank System

In order to achieve low cost and green, only one pump is used in the overall design. It connects the reserved tank to the culture tank. Pump will be triggered automatically when water level of reserved tank reaches the pre-set level. Water passes through from path 1 and path 2 by using natural gravity force because of the difference in height. The flow chart of the water flow is shown in the below Figure 3.

International Journal of Engineering and Applied Sciences

www.eaas-journal.org

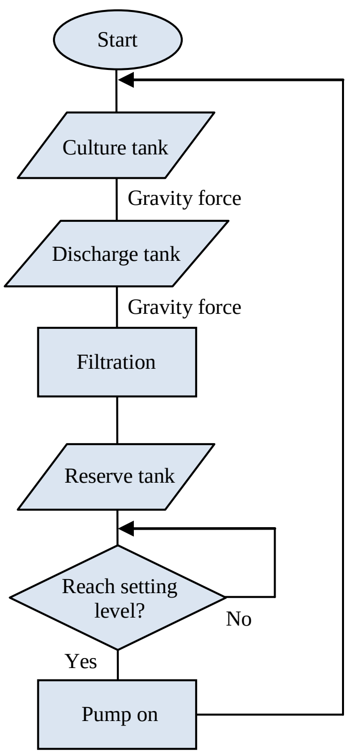

Figure 3: Water Flow Direction

3.2.1 Culture Tank

The shape of culture tank is circular with a sloping bottom because circular tanks provide uniform water quality and are good for culturing. Fish have the nature swim against the current, a circular tank can provide uniform rotational flow and for better culturing. With a properly designed water inlet and outlet structure, the flow is operated with rotating flow about the centre drain. Rotational velocity can carry out solids waste and tank self-cleaning.

The dimensions of culture tank are 240 cm diameter × 120 cm depth with a slope bottom. The tank volume can hold 5400 litersof water and it is economically feasible. Normally, the water volume of culture tank is filled 70% of the total capacity of the tank and the capacity of culture tank is 3800 liters.

Recirculation systems utilize a very small area and allow the grower to stock fish at a higher density. Therefore it requires a high level of water quality. The fishes are housed within the tank and the water is exchanged continuously to guarantee optimum growing condition and reduce the risk of catastrophic losses from disease. For RAS, the circulation rate of water is recommended at least 1 cycle per hour [10]. The outlet flowrate of culture tank can be determined by using equation (1).

$$Recirculation = \frac{Flow\ rate}{Water\ volume} \quad (1)$$
$$= \frac{1}{h} \times \frac{h}{60min} \times 3800l = 63.33\text{l/m}$$

Therefore, the outlet flow rate of culture tank is 63.33L/min.

3.2.2 Discharge Tank

Rectangular discharge tank is proposed (150cm × 125cm × 100cm) because of its lower construction cost compared to the circular tank. Its capacity is 1500 liters. The discharge tank is used for collection of solid waste. It is easy to be maintained with smaller size.

3.2.3 Reserve Tank

The rectangular shape is proposed for the reserve tank. In the recirculation system, the water volume of reserve tank must be at least 25% of the total volume of culture tank [10]. The reserved water is used as a buffer when the dirty water is treated in the discharge tank. The water in reserve tank is used to replace the water in culture tank. The water capacity of reserve tank is 12000 liter.

3.2.4 Material

Polyethylene (PE) is selected for the material of tank because it can last longer than other materials. In additional, it is cheaper than stainless steel and fibreglass. The characteristic of PE can be summarised as light weight,high impact strength, excellent chemical resistant, good heat stability, low permeability of water, taste free,toxic free and soft and stiff.The specifications of project components are summarized in the appendix.

3.3 Piping System

The overall piping connection is shown in Figure 4.

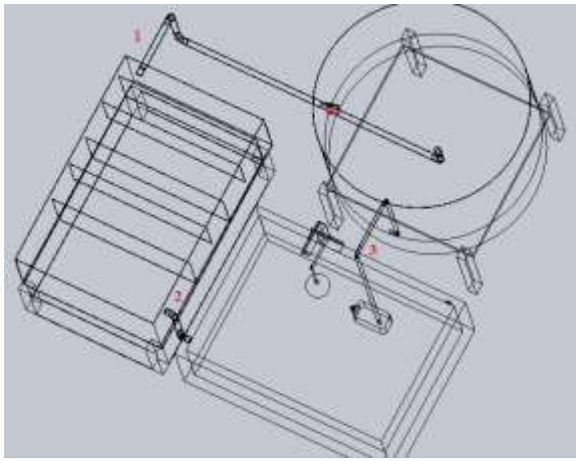

Figure 4: The Piping Structure

Point 1: water flows from culture tank to discharge tank. Point 2: water flows from discharge tank to reserved tank. Point 3: water flows from reserved tank to culture tank.

3.3.1 Culture Tank Inlet Flow Structures

The water inlet pipe is submerged as shown in Figure 5. The water flows out tangential with the wall of culture tank and it creates a uniform rotational velocitywhich provides better self-cleaning and effectively leadsthe solid wastes to the center of the drain.

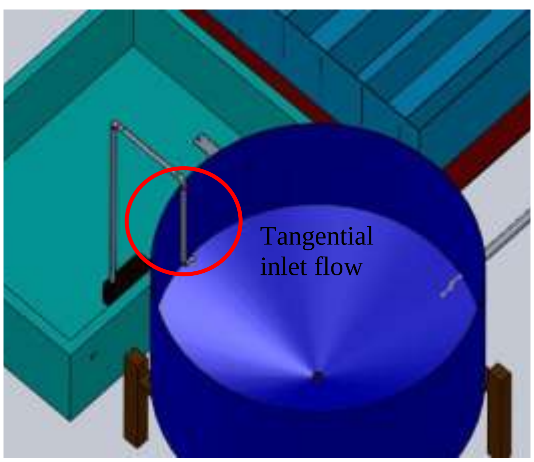

Figure 5: Tangential Inlet Flow

3.3.1 Culture Tank Outlet Flow Structures

The drain is located at the bottom of the tank. It is useful for removing the suspended solids to the discharge tank when suspended solids are accumulated at the bottom. Due to water delivered by gravity force from the culture tank to the discharge tank, pump malfunction will cause the water to overspill; hence water level control is important. The water level is controlled and it represented as a red line as shown in Figure 6. If the pump breaks down, water in the culture tank can be sustained because both tank water levels are same.

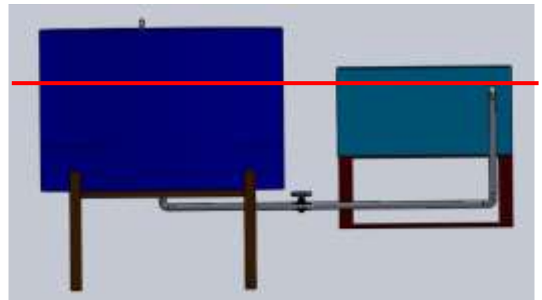

Figure 6: Flow Structures

3.4 Inclined Plane Angle of Tank

Conical tanks have the functionality of self-cleaning action naturally. When the water swirls around the tank, solid wastes are drawn towards the middle, where the outlet is located. Due to this property, self-cleaning tank is designed to remove the solid wastes as soon as possible before they break down.Inclined plane angle can be determined by analysing the force of the solid in the fluid. The total net force of object should be greater than zero.The following equation of net force as below:

$$Net\ force = inersia\ force + total\ gravity\ force + resistance\ force$$
$$= \rho A(V_1^2 - V_2^2) + (\rho_s - \rho)gVsin\theta - F_A (1)$$

Where,

$Inersia\ force = \rho A(V_1^2 - V_2^2)$
$total\ gravity\ force = (\rho_s - \rho)gVsin\theta$
$resistance\ force = F_A$
$\rho = water\ density$
$\rho_s = density\ of\ the\ solid$
$V_1 = velosity\ of\ solid\ at\ point\ 1$
$V_2 = velosity\ of\ solid\ at\ point\ 2$
$F_A = force\ to\ overcome\ gravity$

Solid in the liquid consist of two forces which are the forces of movement and resistance. The force of movement is a force that drivesthe solid to move. It can be divided into inertia of the object and gravity force in this case. The relationship is shown as Figure 7. Parameter v_1 and v_2 must be verified in order to determine momentum of solid. The function of the computational fluid dynamics is to study and

International Journal of Engineering and Applied Sciences

www.eaas-journal.org

analyze fluid flow problems. CFD software can be used to determine v_1 and v_2.

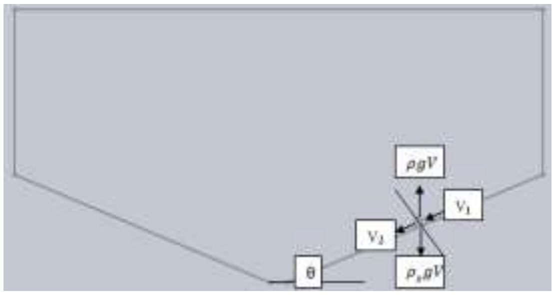

Figure 7: Free Body Diagram of a Solid in Fluid

Equation of $F_A$is shown as below, angle θ mustbe determined in order to get force A.

$F_A = mgsin\theta$

After rearranging equation (1), inclined plane angle is

$$\theta = sin^{-1}\frac{F_A - \rho A(V_1^2 - V_2^2)}{(\rho_s - \rho)gV} \qquad (2)$$

3.4.1 Computational Fluid Dynamics

Computational Fluid Dynamics (CFD) is a well-established and proven method or tool for simulating and studying fluid flows in the subjects involving fluid, heat and mass transfer in different conditions. CFD helps to find an approximate and accurate solution of fluid flowproblems. There are many CFD software in the market, for example Solidworks, Siemens NX, and Fluent and Gambit. In addition, CFD simulation software is also applied to determine the flow trajectory of the water in a tank.

4. Result and discussion

4.1 Geometry of Tank

The slope is fed into the center of tank and solid wastes are collected to the discharge tank (filter). Stagnant or dead areas of the tank can affect the circulation of water through the filter. One of the aims of this project to study how various shape of tank can contribute to the flow of water in the tank. Simulations had been carried out to study the different effects between the flat bottom and slope bottom. The results are shown in Figures 8 and 12. Figures 8 and 9 represent the flow trajectory on the flat bottom of the culture tank. After simulation by using SolidWorks 2010, the dead areas where the water is not moving (red circles)can be observed at the edge of tank. In static state, fish faeces or suspended solids are difficult to be flushed out and it sinks to the bottom of the tank (dead area). Therefore, the bottom contour of the tank is important in order to clean the wastes. One of the disadvantages of having flat bottom tank is that it requires vacuum constantly to keep tank clean.

On the other hand, the inclined contour makes the tank self-cleaning. 10°, 20° and 30° of inclination of the tanks are shown in Figures 10, 11and 12 respectively. The fish faeces or suspended solids on the sloping surface can be easily led to the centre outlet. In the following section, the minimum inclined plane angle will be determined.

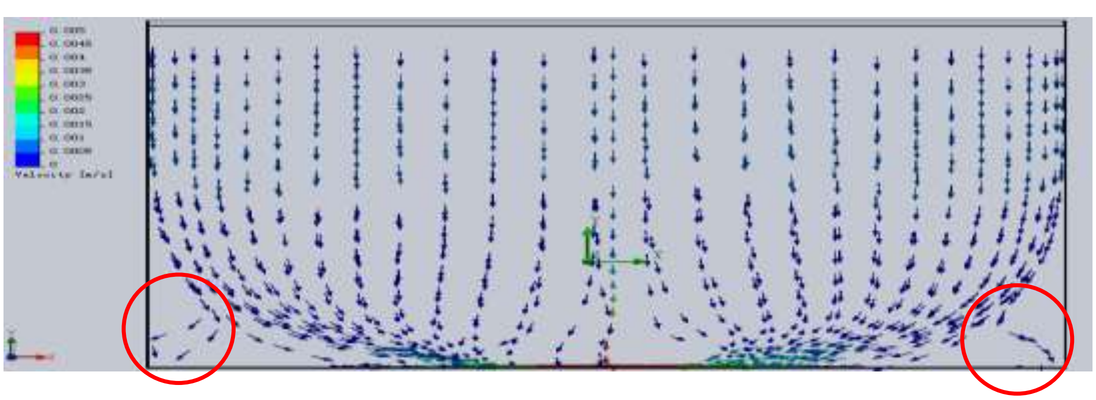

Figure 8: Flat Bottom

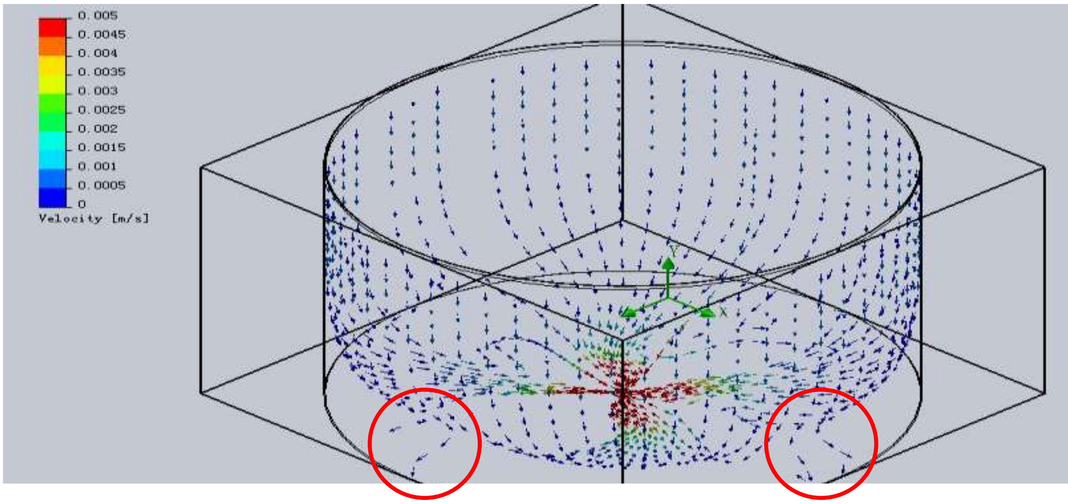

Figure 9: Flat Bottom with Isometric View

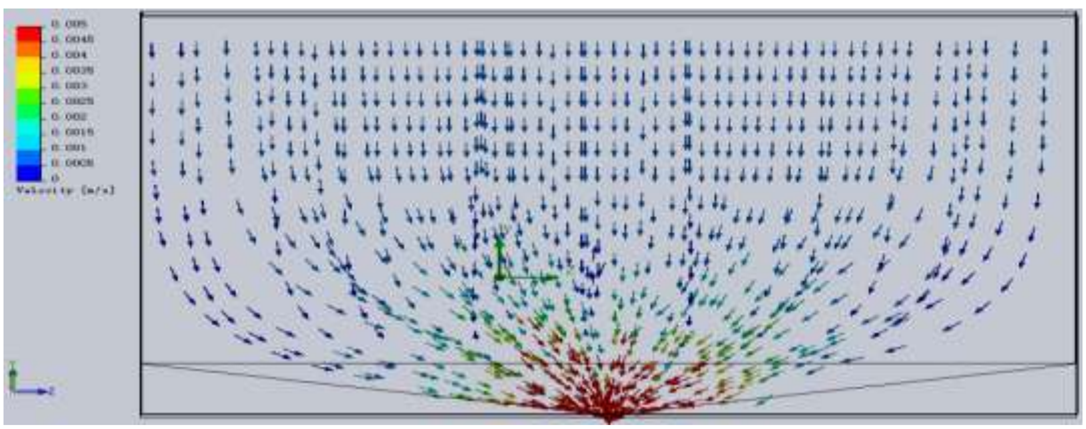

Figure 10: 10^{o} of Inclination

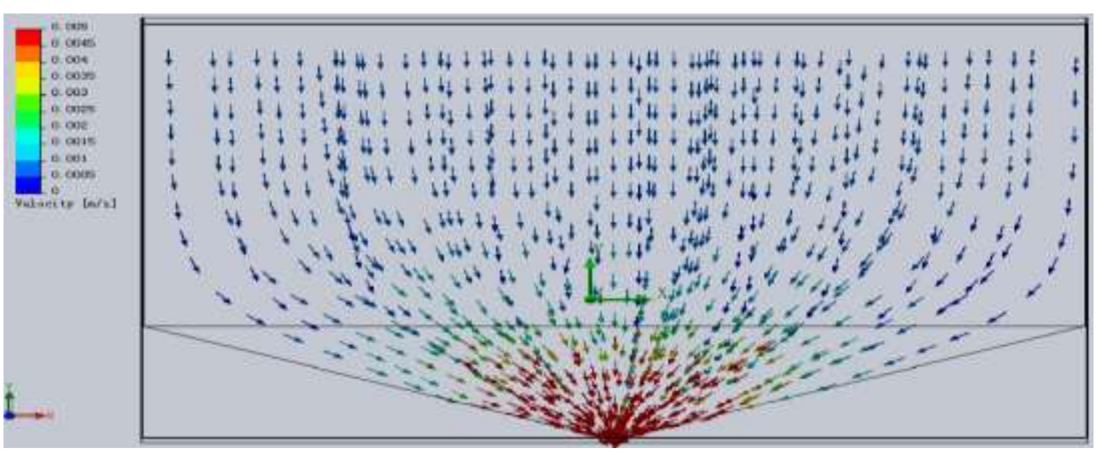

Figure 11: 20^{o} of Inclination

International Journal of Engineering and Applied Sciences

www.eaas-journal.org

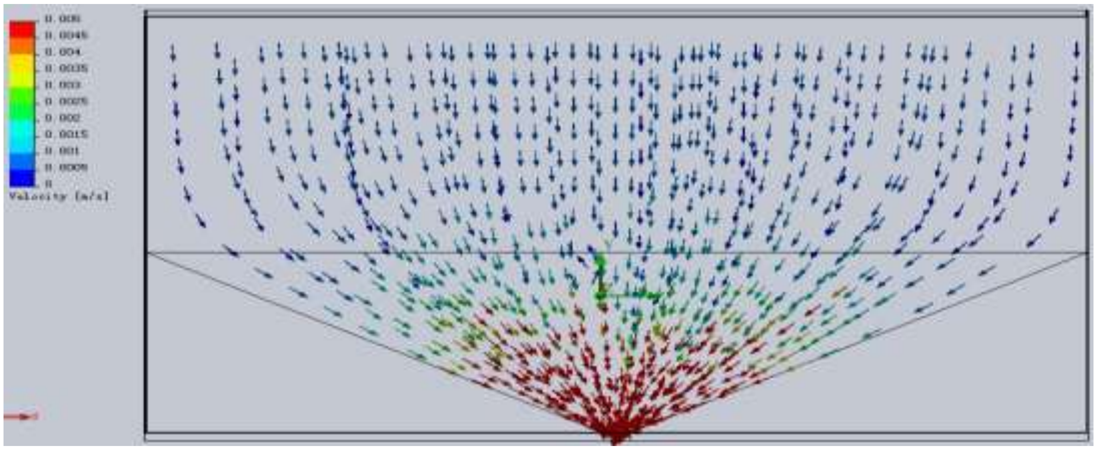

Figure 12: 30^o of Inclination

4.2 Inclined Plane Angle of Tank

In order to analyze and determine solids in the fluid, CFD was studied using Siemens NX 7.5. The minimum inclined plane angle can be determined by using equation (2) in the previous section. The net force of the solid must be greater than zero and the results are shown in the following sub-sections.

4.2.1 Driving Force

v_1 and v_2 were determined by CFD without fish and at exchanges of 1418.6 liters per hour and outlet velocity of 2.89 m/s. Besides that, some assumptions had been made and they were:

I. Assumed that particle at the middle of sloping bottom as shown in Figure 13.
II. Took a sample of fish pallet and its volume was 130.67×10^{-9} m^3 with a diameter of 0.61 cm
III. Density of the fish pallet ρ_s was 1100 kg/m^3

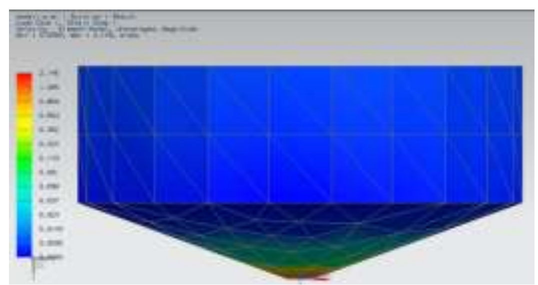

Figure 13: The PositionOf The Solids

The velocity of point 1 and point 2 were computed when the solid and the fluid were flowing simultaneously. As a consequence, the sizes of fish pallet or faecesweretoo small compared with the size of the culture tank. It required more time and effort to observe the velocity after the simulation. To simplify the observation, a "dismantlement" method was used to determine the velocity of point 1 and point 2. Firstly, the position of the solid (red colour) was assumed as shown in Figure 13. From the colour bar, the velocity at the area was roughly 0.058 m/s. Secondly, the geometry of the model was redrawn and simulated once more after all the boundary condition had been defined as shown in Figure 14.

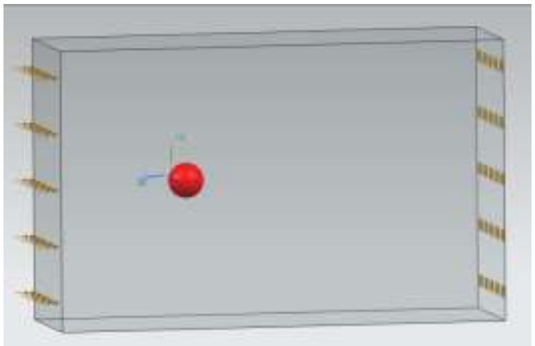

Figure 14: Isolated Solid from Environment

After simulation, the results are shown in Figure 15. It is compared with the colour bar as reference. However, the particle is too small and it is difficult to observe its colour. Therefore, the cutting planes' view is enlarged as shown in Figure 16. As a result, the colour bar can be observed easily. Velocities at point 1 and 2 are 0.0077 m/s and 0.0039 m/s respectively.

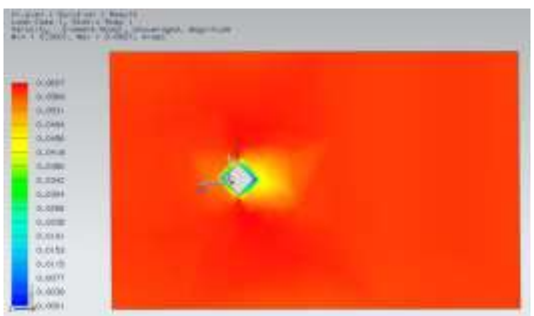

Figure 15: Cutting Plane

Figure 16: Enlarge the Cutting Plane

4.2.2 Resistance Force

F_A (sliding force) can be determined by the method as described in previoussection. It was assumed that the solid sample was the fish pallet and it weighs about 0.0928 g.The average sliding angle was 29°.

$$F_A = mgsin\theta$$
$$= 92.8 \times 10^{-6} \times 9.8 \times sin29°$$
$$=4.409\times 10^{-4} N$$

4.2.3 Inclined Plane Angle

The following values are obtained from the previous sections:

V_1 =0.0077 m/s and V_2 =0.0039 m/s
F_A= 4.409× $10^{-4}N$
V = 130.67×10^{-9} m^3
ρ = 1000 kg/m^3
ρ_S= 1100 kg/m^3

Substitute all the values to equation (2),

$$\theta > sin^{-1}\frac{F_A - \rho A(V_1^2 - V_2^2)}{(\rho_s - \rho)gV}$$
$$\theta > 18.38° \qquad (3)$$

The minimum inclined angle was determined and its angle was 18.38° . After determiningthe inclined angle, an angle of 20°was used to ensure that waste will definitely fall into bottom of the tank. Figure 17 shows the conical shape with 20°.

Figure 17: Conical Shape

4.4Completed Prototype

The prototype was completed and it is shown in Figure 18.

Figure 18: Prototype of the RAS

International Journal of Engineering and Applied Sciences

www.eaas-journal.org

4.4.1 Submerged Inlet Flow Pattern

Two types of submerged inlet system had been tested in the experiments. This test was conducted inside the culture tank without fish and using a pump with flow rate of 5000 L/hour. Figure 19 and 20 shows the normal flow pattern and tangential flow pattern respectively. The normal water inlet flow is inefficient and poor because the flow of water is divided by four. The velocity is reduced so the normal flow pattern design is inefficient in self-cleaning. The tangential inlet flow provides stable and uniform rotational flow at all flow rates. This moves particles along the sloping bottom and particles are easier to be discharged. Figure 20 showsthe rotational flow is generated and effectivelyfor self-cleaning. Black colour arrow represents the inlet flow direction. The dirty water is shown in Figure 21. After 5 minutes of processing time, the wastes are cleaned automatically as shown in Figure 22.

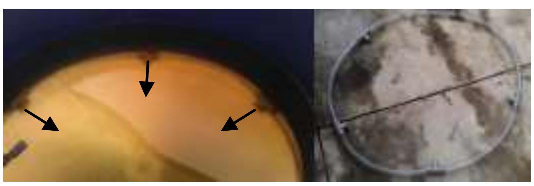

Figure 19: Normal Flow Pattern

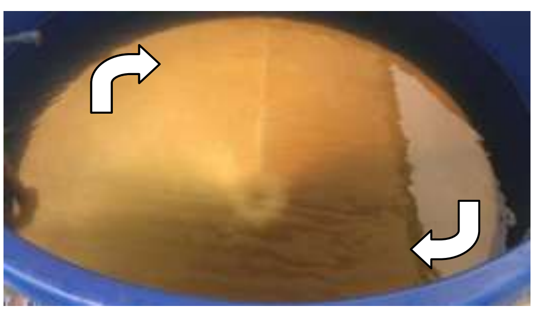

Figure 20: Tangential Flow Pattern

Figure 21: Dirty Water

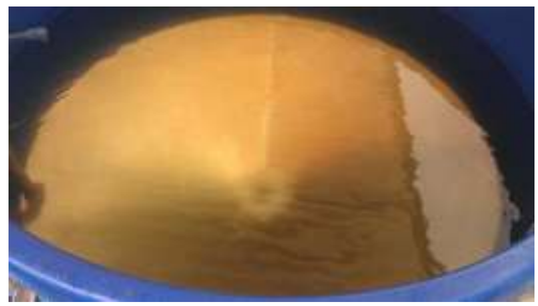

Figure 22: Wastes Are Removed

4.4.2 Flow Control

The rotational velocity in the culture tank should be swift to make the tank self-cleaning. However, rotational velocity cannot faster than that required to exercise the fish as discussedin the section 2. Furthermore, fish pallet will be flushed to the outlet by the tornado effect.

Figure 4.22: Tornado Effect

This experiment was conducted to find out optimum outlet speed for self-cleaning. Outlet speed was controlled by the manual valve. The results are summarized in Table 1. It could be concluded that optimal outlet speed is 20 to 30m/s. While outlet speed is more than 30m/s, fish pallet would be swirled away to outlet by the tornado effect. In additional, the velocity is also not suitable for fish growth.

Table 1 : Results of Vary Outlet Speed.

Outlet speed (m/s)	Comment
Less than 20	Poorer in self cleaning
20 to 30	Optimal speed for self cleaning
More than 30	Not suitable and create “tornado” effect

5. Conclusions

The CFD analysis was carried out using SolidWorks 2010 and Siemen NX7.5. Self-cleaning tank was developed by having the inclined angle at 20° and settleable solids can be easily flushed through the center drain. The design of tangentially flow pattern provides rotational flow and swirling flow pattern in a conical shape tank. The tangential flow design increases solids removal efficiency. However, rotational velocity should not be faster or else it will create the “tornado” effect and make harmful to the culture environment. Optimal velocity for self-cleaning is ranged 20 to 30 m/s.

6. Appendix

Component	Description	Capacity
Culture Tank	Circular with sloping bottom,240 cm ×120cm	3800 Liter
Discharge Tank	Rectangular 50cm× 125cm× 100cm	1500 Liter
Reserve Tank (3 set)	3 x (200cm × 150cm × 150 cm)	12000 Liter
Total fish weight in culture tank	Fish density 80kg/1000L Water volume 3800L	300 kg of fish
Mass consumption Oxygen consumption	Fish weight 0.3~300 kg of fish Feeding rate 6~2%	1.8~6 kg of feed per day
Air Blower (Aeration system)	Mass consumption 6 kg/day Oxygen requirement 0.25 kg O2/kg feed	1.5 kg O2 per day
Air Blower (Aeration system)	Oxygen consumption rate, 0.0625 kg/h Oxygen transfer rate,0.455 kg/kw.h	0.1374kw

7. References

[1] Menasveta,P., Panritdam,T., Sihanonth,P., Powtongsook,S., Chuntapa,B., and Lee,P, “Design and function of a closed, recirculating seawater system with denitrification for the culture of black tiger shrimp broodstock”, Aquacultural Engineering, vol. 25, pp. 35-49, 2001.

[2] Steven T. Summerfelt, Gary Wilton, David Roberts, Tina Rimmer and Kari Fonkalsrud, “Developments in recirculating systems for Arctic char culture in North America”, Aquacultural Engineering, vol. 30, pp. 31–71, 2004.

[3] M.A. Franco-Nava, J.P. Blancheton, G. Deviller, A. Charrier and J.Y. Le-Gall, “Effect of fish size and hydraulic regime on particulate organic matter dynamics in a recirculating aquaculture system: elemental carbon and nitrogen approach”, Aquaculture, vol.239, pp. 179–198, 2004.

[4] IlanHalachmi “Systems engineering for ornamental fish production in a recirculating aquaculture system”,Aquaculture, Volume 259, Issues 1–4, 8, Pages 300-314, 2006.

[5] IdoSeginer and Noam Mozes, OriLahav “A design study on the optimal water refreshment rate in recirculating aquaculture systems”, Aquacultural Engineering, Vol. 38, No. 3, pp, 171-180, 2008,

International Journal of Engineering and Applied Sciences

www.eaas-journal.org

[6] Shi-Yang Zhang, Gu Li, Hui-Bi Wu, Xing-Guo Liu, Yan-Hong Yao, Ling Tao and Huang Liu, "An integrated recirculating aquaculture system (RAS) for land-based fish farming: The effects on water quality and fish production", Aquacultural Engineering, vol. 45, pp. 93– 102, 2011.

[7] MaddiBadiola, Diego Mendiola and John Bostock, "Recirculating Aquaculture Systems (RAS) analysis: Main issues on management and future challenges", Aquacultural Engineering, vol. 51, pp. 26– 35, 2012.

[8] William Johnson and Shulin Chen, "Performance evaluation of radial/vertical flow clarification applied to recirculating aquaculture systems", Aquacultural Engineering, vol. 34, pp. 47–55, 2006.

[9] Hutchinson, W.Jeffrey, M.O'Sullivan D, Casement D, & Clark, S., "Recirculating aquaculute system Minimum Stardard for Design,Construction and Management", Australia: South Australia Reserch and Development Institute, 2004.

[10] Helfrich, Louis A. and George Libey, "Fish Farming in Recirculating Aquaculture Systems", Department of Fisheries and Wildlife Sciences, Virginia Tech, Virginia, 2003.

[11] Michael B. Timmons, Steven T. Summerfelt, Brian J. Vinci, Review of circular tank technology and management, Aquacultural Engineering, vol. 18, pp.51–69, 1998.

[12] Joan Oca and Ingrid Masalo, "Flow pattern in aquaculture circular tanks: Influence of flow rate, water depth, and water inlet & outlet features", Aquacultural Engineering, vol. 52, pp. 65– 72, 2013.

[13] Steven T. Summerfelt, John Davidson, Grover Wilson and Thomas Waldrop, "Advances in fish harvest technologies for circular tanks", Aquacultural Engineering, vol. 40, pp. 62–71, 2009.

[14] Andrew S. McRobbie and Andrew P. Shinn, "A modular, mechanical rotary device for the cleaning of commercial-scale, circular tanks used in aquaculture", Aquaculture, vol. 317, pp 16–19, 2011.