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Investigation of solid removal of the Cornell design tank by using submerged vanes

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Abstract

Many scientists have been studied on water quality and solid removal from Recirculating Aquaculture Systems (RAS), but the solid removal problem did not solve completely yet. This paper is based on experimental data on a cylindrical tank in diameter of 0.53 m and height of 0.17 m and inlet flow using six nozzles in 2 mm diameter to determine solid removal efficiency by comparison with some different scenarios. The results indicate that using submerged vanes on the bed of the tank may improve removal of solid particles. In this paper 10 different scenarios compared and some of them showed more effectiveness on solid removal. The number of submerged vanes in outer pyramid of the tank bed does not necessarily reduce amount of sediment discharge efficiency, and the location of each vane makes a special impact on the context of hydraulic conditions and solid removal as well. The experimental observations showed, the second scenario (12 submerged vanes in binary groups) and the third scenario (7 submerged vanes in 45º by the vicinity of the tank wall) have significant impacts on sediment discharge efficiency.

Keywords: Settling pattern, Cylindrical tanks, Recirculating aquaculture systems, Hydraulic model, Fish feed.

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Introduction

Several studies have been done on recirculating aquaculture system so far (Rafiee *et al*., 2006; Rafiee and Saad, 2008; Ljubobratović et al., 2016). Accumulation of suspended and dissolved solids oriented both from uneaten and indigested feed are considered as restricting factors for more production of fish in a recirculating aquaculture system (Rafiee and Saad, 2008). In order to remove the solid particles in aquaculture systems, an eco– trap recirculating system designed. In Eco-trap of cylindrical aquaculture system the solid trap efficiency, increased more in comparison with other aquaculture systems due to the flow pattern in cylindrical tanks. In this system, most of the solid particles release from central outlet and discharge to settling tank and few parts of particles that flow from lateral outlet move to drum filter to separate solid materials from liquid. The density of uneaten food and fish feces are more than water density and required for more detention time to deposit.

Settlement of uneaten food and feces develop an organic condition on the bed, and decomposed by anaerobic bacteria and increases infectious condition. By altering the physical shape of the particles to finer gel particles, removal of solid makes more difficult.

The rotational velocity in the culture tanks should be as uniform as possible and it should be rapid enough to make the tank self-cleaning, but it should not be faster than that required to exercise the fish. Water velocities of 0.5–2.0 time's fish body length per second (between 1-2 body lengths per second for Salmons) are optimal for maintaining fish health, muscle quality, and respiration (Losordo and Westers, 1994). Velocities needed to force settleable solids to the tank center outlet should be larger than 15 to 30 cm s^{-1} (Burrows and Chenoweth, 1970; Mäkinen *et al*., 1988).

The current velocity in a tank can be organized by changing the inlet impulse force (Tvinnereim and Skybakmoen, 1989). Also based on Labatut *et al*. (2006) results the flux of momentum is the motivating force adjusting rotational velocities in a jet-forced circulation vessel. On the other hand, in 'Cornell-type' dual-drain tanks the water velocity decreases as the fish swim closer to the middle of the tank, which allows fish to select what velocity they want to swim against by moving to different positions in the culture tank.

Settling velocity of extra fish food and fecal particles in the Cornell design tank is related to solid characteristics such as density and shape of solid particles and current pattern. Based on Komar (1980) experiments on the settling rates of cylindrical-shaped grains in a fluid, having application to the settling of certain heavy minerals and fecal pellets in water. Analysis of the data shows that the settling velocity ω_s can be calculated with the modified Stokes relationship.

There are a number of shape factors available in the literature to describe the deviation of non-spherical particles to spheres. Dynamic shape factor (v) is the

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most suitable parameter for flow applications as it takes into account the dynamic properties of the non-spherical particles (Lau and Hong, 2013).

A general formula for the settling velocity of a particle, presented by Camenen (2007) that applied to any particles. The three coefficients in the proposed equation were fitted for different shape and roundness. Also, Concha (2009) defined the relationship between the two parameters of dimensionless velocity and dimensionless size of particles.

In this paper, the flow velocity pattern and sedimentation pattern in the cylindrical tank, for the various flows and numerous arrays of submerged vanes has been tested without the presence of fish. The hydraulic laboratory experiments have been supported in Soil Conservation and Watershed Management Research Institute. Obviously, the results of this study need training in the tank by attendance of fish in the pilot plan to monitor fish growth process.

Materials and methods

Conceptual basis

Physical models

Similarity of flow characteristics in the physical model could be possible when the mechanical simulation (consists of geometric, kinematic and dynamic simulations) will be installed between the model and prototype. In geometric similarity of a tank, the size and mass of tanks are concerned, i.e. the ratio between length scales of prototype and model will be constant. At Kinematic similarity of the tank, the flow velocity is concerned, i.e. the ratio between the flow velocity in the model and prototype scale will be constant and in dynamic similarity, associated with similar forces, in other words, the ratio between the model and prototype scale of tank forces will be constant. The results of tanks hydrodynamic analysis show that the Reynolds number (the ratio of inertial forces to viscous forces) and Froude number (the ratio of inertia forces of gravity) are the main criteria for establishing similarity between the model and prototype. Because of high Reynolds number and viscosity often is low, thus, the similarity usually created by the Froude number.

To take on the desired water rotational velocities and tank mixing effects in the tank pointing the eject jets at approximately 45 degrees (from the tank tangential) is practically efficient. Hence, the effective strength of the submerged jet in the water cycle is applied. This component of the water rotation, becoming compulsory and is influenced by external powers.

Submerged vanes

A theoretical design basis for submerged vanes presented by Odgaard and Kennedy (1983) , Odgaard and Spoljaric (1986). Odgaard and Kennedy’s attempts were aimed at designing a system of vanes to stop or reduce bank erosion in river curves. In such an application, the vanes are laid out so that the vane generated secondary current eliminates the centrifugal induced secondary current, which is the root cause of river bank undermining. The vanes stabilize the toe of the river bank.

The vanes are small, submerged structures designed to modify the near-bed flow pattern and redistribute flow and sediment transport within the channel cross section. Fig. 1.a shows the orientation and location of high and low pressure zones within a curved channel reach. α is the vane angle of attack with respect to the bend flow, b is the bank full channel width, r_i and r_o the inner and outer radius respectively, and L the length of the vane. The counter-current vortices emerge and are carried downstream as flow passes over the vane. The structures are installed at an angle of attack of 15-25 with the flow, and their initial height is 0.2-0.4 times the local water depth at design stage. It was recommended that in order to produce strong vortex currents in a straight stream, the transversal distance between the vanes must be less than 2h-3h ("h" is the vane height above the stream bed) and with longer distances the vanes will create a single vortex.

Also the longitudinal distance between vanes should be 15h-30h that, depends on the location and geometry of the stream. The distance to wall also should not be more than 4h. The vanes function by generating secondary circulation in the flow. The circulation affected by the vanes changes degree and direction of the bed shear stresses and causes alter in the distribution of velocity, depth, and sediment transport in the area.

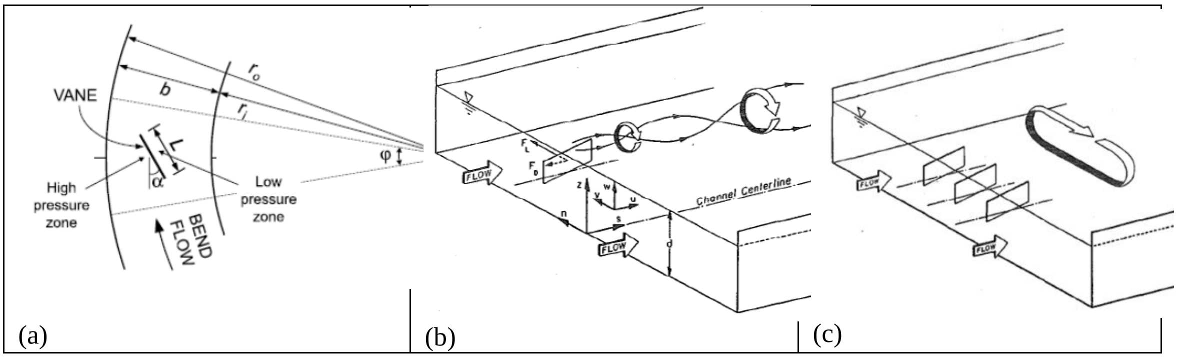

Figure 1: (a) Typical vane orientation and location of high and low pressure zones (Voisin and Townsend, 2002) (b) Schematic of flow situation showing vane-induced circulation (Odgaard and Wang, 1991) (c) Schematic showing circulation induce by array of three submerged vanes (Odgaard and Wang, 1991).

Vanes are distributed in arrays (groups) along part of the channel. When the vanes are submerged, they induce a transverse force and torque on the flow and cause a longitudinal vortex at their tops (Fig. 1.b, 1.c).

Another application of submerged vane is in the vortex settling basin. Such basins represent the higher speed in sediment separation in comparison with other usual settling structures. One of the problems of such settling structure is the settlement of a fraction of the sediments on the basin floor as a result of disturbance on the structure operation.

Several curvature vane patterns were applied in an experimental model of the

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vortex settling basin to explore the efficiency and sediments removal from the basin floor. Experiments were carried out in a basin with a diameter of 96 cm and a height of 206 cm. In this model, curvature submerge vanes were used for adjustment and their different arrangement in 60 degree diameter section for increasing in vortex power. Experiments were continued by 45 and 37 L s^{-1} water discharge, flushing orifice diameters of 36, 46 and 59 mm and six different arrangements of vane R2, R3, R4, R23, R34 and R234 (Fig. 2). Results showed that application of submerged vane on the vortex basin floor with suitable arrangement resulted in sediment removal from the basin floor and in replacement of sediments toward the orifice. Present research showed that the best efficiency was obtained from R3, R4 and R34 arrangements which were located in the further distance from the orifice.

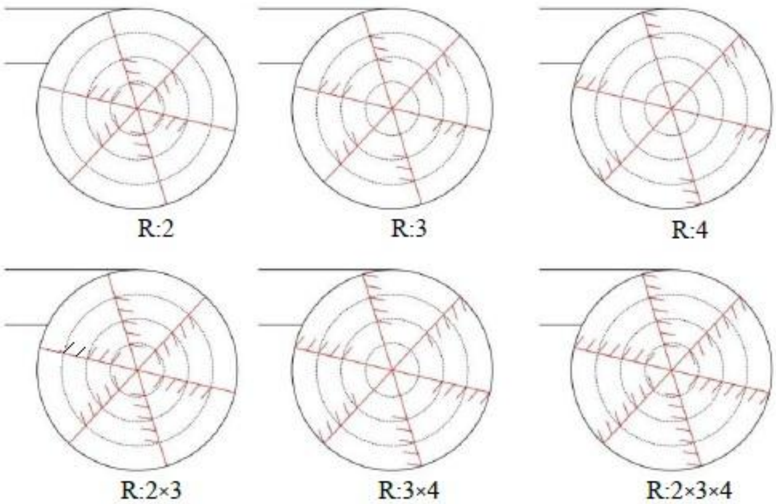

Figure 2: Six different arrangements of vane on the bed of settling basin.

Using submerged vanes helps to change beneath flow pattern due to changes of pressure on two sides of submerged vane. As flow reaches the vane, a counter-circulation develops as a result of the pressure gradients across the vane. The pressure decreases from bottom to top on the upstream (high pressure) face; while on the downstream (low pressure) face, pressure increases from bottom to top. As fluid flows over the vane, these pressure regimes trigger the formation of vertical vortices that counteract the naturally occurring secondary circulation (Odgaard and Wang, 1991). As the vortices are carried downstream, this secondary flow is responsible for changes in shear stress and bed topography.

Cylindrical fish tank and connected installations

At first, the tank was planned to study the hydraulic conditions in the cylindrical fish tank. The tank with a diameter of 0.53 m and a height of 0.17 m was designed and constructed (Fig. 3). The water flowing through the inlet nozzles (6 nozzle diameters matched 3mm) set at an angle of 45 degrees to supply 'Cornell-type' dual-drain tank.

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Required water pumps from main tank to 'Cornell-type' dual-drain tank by a circulating system. The overflow passes through the side weir of the tank. After establishing a steady and constant flow and constant water level in the cylindrical tank, sprinkled pellets over the surface water of tank manually. Few parts of sprinkling pellets were settled and most part of them was removed through the orifice embedded in the middle of the cylinder tank bottom. At the end of each test, to determine the settlement pattern and removal efficiency of sediments in the cylindrical tank, water of the tank has been emptied slowly and after weighting the settled sediments for different scenarios, the effects of the vanes evaluated in different arrays on the removal efficiency of pellets.

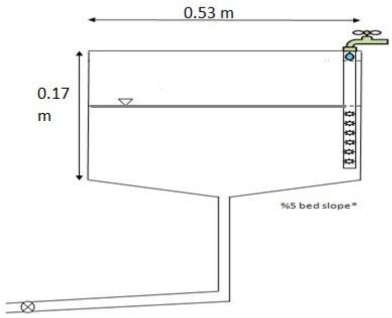

Figure 3: Typical scheme of laboratory 'Cornell-type' dual-drain tank.

At this tank sediment discharge efficiency can calculate by the following formula:

$$RE(\%) = \left[\frac{S_{in} - S_{out}}{S_{in}}\right] \times 100 \qquad (1)$$

Where RE% is central sediment discharge efficiency, S_{in} is average inlet sediment in the tank and S_{out} is the amount of sediment deposited on the bed.

Results

The results of submerged vanes application in a cylindrical tank show that the velocity in different depth and radial layers of the tank is changed due to secondary flow in the pyramid of the tank and vortices in the center of tank. Although the current flow for some vanes makes settling condition to deposit sediments on the side of the vane by lower pressure, difference of pressure on both sides of vanes makes local eddies toward the central outlet. In Fig. 4 one sample of sedimentation tests in cylindrical tank has shown.

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Figure 4: Sample of sedimentation in cylindrical tank.

Table 1 shows the deposition of sediments in the bed of the cylindrical tank and the sediments discharge efficiency of the central output for different scenarios. In this table sediments discharge efficiency for each sample of settled sediments is calculated by the following formula (1).

Table 1: Laboratory scenarios for application of submerged vanes in different array.

	Options	%RE
1	Control option (No vanes)	19
2	12 S.V. in binary groups	60
3	7 S.V. in 45º by the bank	58
4	Two S.V. on the bank	38
5	18 S.V. in binary groups	37
6	8 S.V. in 45º by the bank	25
7	2 S.V. in the bank and 2 on the bed	24
8	7 S.V. in the bank and 5 on the bed	19
9	2 S.V. in the bank and 3 on the bed	18
10	2 S.V. in the bank and 1 on the bed	17

By observing the behavior of sediment deposition and sediment discharge efficiency for different scenarios by application of submerged vanes in different arrays, ordering vanes in Fig. 4 is planned. New scenarios selected based on observation of settling behavior in the former experiment. For example, if sediment traps on the back of a submerged vane, that the vane is removed in next experiment and the test is repeated with the same hydraulic conditions. Fig. 4 shows, laboratory scenarios range from top to the bottom in order of highest to the lowest percentage of their sediments discharge efficiency as Table 1.

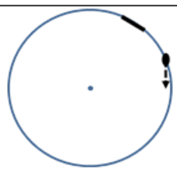
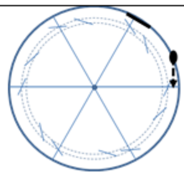
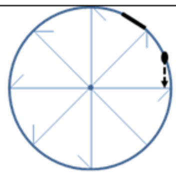
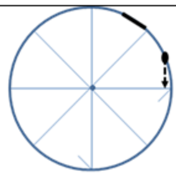
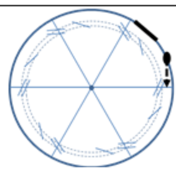
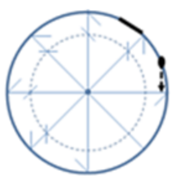
Record	1	2	3	4	5
Vanes array scenario					
RE	0.19	0.60	0.58	0.38	0.37
Record	6	7	8	9	10
Vanes array scenario					
RE	0.25	0.24	0.19	0.18	0.17

Figure 4: sediments discharge efficiency of different scenarios for application of submerged vanes in different arrays.

Discussion

In this study, the innovation of the application of submerged vanes in the cylindrical tank is confirmed as the half-radius of reservoir does not apply to the effect of deposition in the reservoir, and this boundary can change related to tank hydraulic condition.

As, Fig. 5 shows, comparison of sediments discharge efficiency from the central outlet between different scenarios, determine that ordering the submerged vanes array can be effective on sediments discharge efficiency. So that, scenarios 2 and 3 have a significant impact on sediments discharge efficiency (about %40 more sediments discharge efficiency than control option), and scenarios 4 and 5 have an average effect (about %18 more sediments discharge efficiency than control option), and the effect of scenarios 6 to 10 on sediments discharge efficiency are insignificant. In spite of this fact that the position of submerged vanes and the location of local eddy effect on sedimentation pattern, the sediments moves toward the center of the tank by using the submerged vanes.

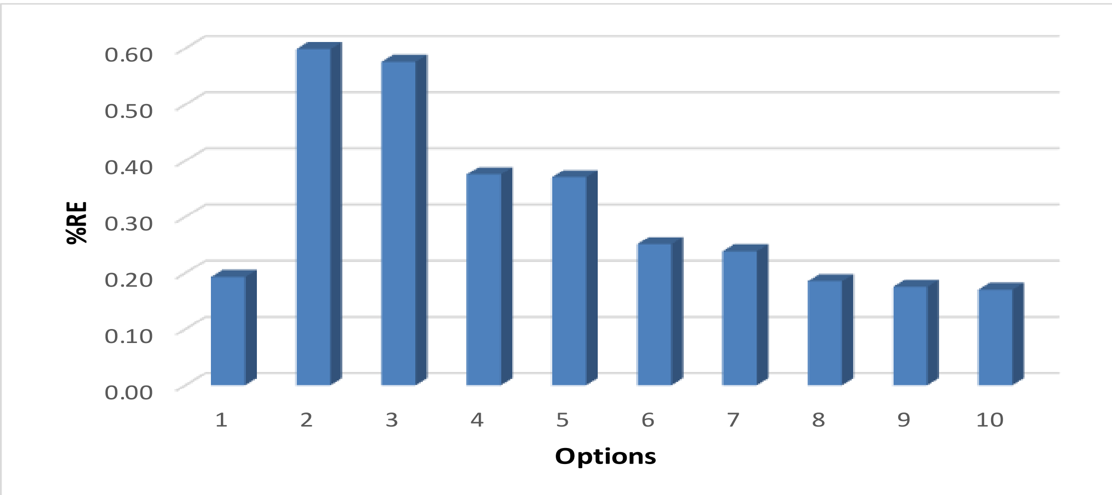


Figure 5: The histogram of sediments discharge efficiency for different scenarios.

By considering the scenario records in Fig. 4, recognizes that operation of current jet in a freely trajectory movement without any barrier makes better secondary flow in the tank and enhanced angular momentum to move sediments toward the central outlet. Also, established submerged vanes that located in the second quarter of the tank from nozzle position and near the inner bank of the tank improve solid removal processes. Finally, the numbers of submerged vanes in the exterior pyramid of the bed in tank, essentially does not reduce the amount of sediments discharge efficiency as discovered in record 8 of Fig. 4, and the location of each vane makes a distinctive effect on the tank hydraulic condition and solid removal as well.

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