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Hydrodynamic effects of use of eductors (Jet-Mixing Eductor) for water inlet on circular tank fish culture

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ABSTRACT

Trials were conducted in circular tanks used in aquaculture (1.2 m diameter and 0.4 of useful depth) in order to evaluate the effect of different water injection devices on the tangential velocity of the water, its uniformity pattern, the mixing time and the removal of solids through the bottom drain. Two injection devices, without fishes, were evaluated at the tank: a Vertical Spray, considered as standard in aquaculture and an eductor (Jet-Mixing Eductor) which is used in chemical and petrochemical industry to homogenize and keep in movement great volumes of water. The devices were evaluated under the same operating conditions: inlet flow of 4, 6 and 8 l/min and water injection angle of 0° and 45°. In each trial, the water velocity inside the tank was measured, also the mixing time and the time in which the 100% of pellets of fish food were eliminated from the tank through the bottom drain. The results indicate that, for all inlet flows, the eductor operating at 45° presents significantly ($p < 0.001$) better result in terms of hydraulic variables such as tangential velocity, uniformity, mixing time and solids removal time from the tank (self-cleaning effect). In the case of eductors, although an increase of inlet flow produces improvements of hydraulic variables, a change of water injection angle, from 0° to 45°, produces significantly better results ($p < 0.001$). Differences of hydraulic performance between the eductor and Vertical Spray are mainly owing to the multiplicative effect of the outlet flow that is generated by the eductor. This means that, for similar values of impulse force and water velocity at the exit of the nozzle injection (V_2), the eductors generate significantly higher tangential velocity and uniformity, lower mixing times and secondary flow patterns, which ensure the self-cleaning of solid waste. In terms of power consumption, eductors overcome Vertical Spray in the trial performed. However, when comparing them under equal requirements of hydraulic performances (velocity, mix and/or self-cleaning), eductors present the same or lower energy consumption. Comparatively eductors would generate, under similar operating conditions, clear benefits for produced species in aquaculture, by generating hydraulic conditions that ensure a better quality of water and patterns and uniformity of velocity, which are more suitable for their health and normal growth.

1. Introduction

The use of large circular tanks to produced fishes in recirculating aquaculture systems (RAS) has become a general tendency in salmon farming industry. This is mainly attributed to the savings obtained by using economies of scale in the use of the workforce and the reduction of capital cost of tanks when the relation (useful/volume)/(tanks number) increases (Timmons et al., 1998). The main operating conditions of these tanks are: (i) to provide an homogeneous culture environment in terms of water quality; (ii) to operate in a wide range of circular velocities in order to optimize both health and muscle tone condition of fishes; and (iii) to concentrate and to remove quickly solids that settle down (i.e. feces and food remains) inside the tank (Timmons et al., 1998; Lekang, 2007). In hydraulic terms, the conditions of velocity and mixing level that are obtained inside the circular tank, with circular flow patterns, are the direct result of the transference impulse force that is exerted on the volume of water contained in the tanks. The impulse force depends directly on: (i) magnitude and direction of the recirculated inlet flow (i.e. injection velocity); (ii) dimensions and shape of the tank; and (iii) capability of water injection devices to transfer the highest quantity of movement (Timmons et al., 1998; Lekang, 2007; Oca and Masaló, 2007). However, if the injected water (new and/or reuse flows) does not properly transform the energy in impulse

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Nomenclature

A	area of the outlet mouth of the eductor
C	water color at any point of the tank
C_t	resistance coefficient of the tank
$\bar{C}$	expected final color of the water when it reaches the full mix (mix = 0.05)
UC_{50}	uniformity coefficient of water velocity (%)
d_j	orifice diameter through which the water exits from the injection device
F	impulse force
h_j	height from the bottom of the tank to the point "i"
O	number of vertical levels which measured velocity
m	maximum allowable deviation between the concentrations to consider the presence of mixed
n	number of horizontal levels on which measured velocity
P_j	power consumed by the injection device
Q_i	flow into the injector, reuse flow rate
Q_o	flow out of the injection system
r_i	horizontal distance from the center of the tank to the point "i"
T_{sr}	time to exit through the bottom center drain 100% of the food
T_{mix}	time in which is homogenized at 95% coloring the tank water (mix = 0.05)
TRH	hydraulic residence time in the tank
V_1	the weighted average tangential velocity of the water on the tank
V_2	water velocity at the exit of the nozzle injection device
V_{50}	average circulation velocity of 50% area with lower values
V_i	water velocity at a point "i" of tank
V_j	velocity of the water jet that is generated by the energy supplied to the injection device

Greeksymbols

ρ	water density
θ	entry angle of the water stream to the tank, in degrees

force (mass flow and variation of velocity), the benefits of circular tanks are wasted, and the formation of local vortexes is favored (i.e. short-circuit zones), which affects the availability of dissolved oxygen, the self-cleaning, dilution of pollutant, and health and normal growth of fishes (Timmons et al., 1998; Watten et al., 2000; Rasmussen et al., 2005; Labatut et al., 2007; Lekang, 2007).

According to the reviews made by Timmons and Ebeling (2010) and Lekang (2007), to obtain adequate levels of mixing and solids removal in large circular tanks, it is necessary to maintain rates of replacement of water at least between 0.6 to 2 times/h. This range can be extended depending on the cultivated species, the design of the tank, the design of injection devices, and elimination of used water. Thus, a tank of 10 m in diameter (200 m^3 of usable volume), will require that their pumping system, treatment and conditioning of water should be designed and dimensioned to move 400 m^3/h, or more if the conditions of water quality puts at risk species in cultivation. This situation has a direct impact on the efficiency of recirculation systems, on space requirements and the power consumption. In this regard, Tyedmers (2000) and Colt et al. (2008), state that the main consumption of power at the RAS is pumping and treatment of water that could reach a 55% of total consumption.

Several studies in the literature show the effect of different configurations of inlet devices on the hydrodynamic of culture tanks (Skybakmoen, 1989; Tvinnereim and Skybakmoen, 1989; Losordo and Westers, 1994; Timmons et al., 1998; Odeh et al., 2004; Lekang, 2007). Some studies focused on the effect of diameter, angle, and number of nozzles in inlet devices on the hydrodynamics generated in tanks (Davidson and Summerfelt, 2004; Labatut et al., 2007; Oca and Masaló, 2007). Other studies show the combined effect of the device configuration of outlet and inlet water over the velocity and mixing time (with or without fishes) (Cripps and Poxton, 1993; Timmons et al., 1998; Summerfelt et al., 2000; Watten et al., 2000; Davidson and Summerfelt, 2004; Rasmussen and McLean, 2004; Ebeling et al., 2005; Rasmussen et al., 2005; Lekang, 2007) and the effect of velocity and mixing time over the fish growth and productivity of culture systems (Losordo and Westers, 1994; Lawson, 1995; Ross et al., 1995; Timmons et al., 1998; Lekang, 2007; Duarte et al., 2011). The research in this field has been mainly focused on the base of a standard injection device, which involves a vertical tube with generic spray nozzles or holes. Although different flow-injection technologies are also available, they have not been evaluated in aquaculture systems. According to this, there are other devices of inlet water that are used in a wide range of industrial process, especially in chemical, petrochemical, and fuel industry that mainly require to keep in movement great volumes of liquids, to avoid decanting, and/or mixing different compounds in a quick and effective way (Harnby et al., 1992; Rahimi and Parvareh, 2005). Some of these devices are the Eductors, also known as Hydraulic Pumps, Coaxial Jet Mixers or Jet Mixer Eductors (Mooney, 2007). Their main feature is to multiply the volume of fluid that passes through them (Stratton, 1976; Harnby et al., 1992; Mooney, 2007) increasing the impulse force generated. Eductors consist of a piece of tube of declining diameter with a nozzle at the exit that is connected an open Venturi bell. When the water flow goes into the eductor, a pressure drop is produced at the exit nozzle thus, the liquid of the tank that surround the eductor is sucked into the Venturi bell, and later it is expelled trough the eductor exit. In this way, the total volume of liquid that is expelled is the sum of the one that comes out of the nozzle at high velocity plus the one that was sucked by the pressure drop (Tamotsu, 1988). The volume sucked through the eductor can be 3–5 times the volume that enters the device (Stratton, 1976; Jacoby-Tarbox, 1999; Schutte & Koerting, 2005; Mooney, 2007; Spraying Systems Co., 2008).

Studies related to the use of eductors in confined aquaculture have not been found in the literature. From this point of view, it seems relevant to study the hydrodynamic effects of eductors on the standard growth of cultured species and determine their operational benefits compared with the standard systems of water injection (power and water consumption, management, space demand, etc.). The objective of this study is to evaluate the hydraulic effects of the use of eductors in circular tanks on the water flow patterns, mixing level, tangential velocity, self-cleaning and uniformity of the water in a circular tank. In addition, the studies will be conducted considering different inlet (reuse) flow and injection angle.

2. Methods

2.1. Test tank

Trials were conducted in a fish culture system with recirculation consisting of (Fig. 1): (i) a circular tank made of glass fiber, 1.2 m diameter, 0.5 m height, with a, central bottom, drain; (ii) an equalization tank of 100 l; (iii) a centrifugal pump (Espa® Iris750M, 0.65 kW); and (iv) an injection system of water. The water flow injected to the circular tank by the injection system is discharged by