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Separation of fine organic particles by a low-pressure hydrocyclone (LPH)

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ABSTRACT

The separation performance of a low-pressure hydrocyclone was tested using fine organic particles from 1 to 700 μm. The dimensions of the low-pressure hydrocyclone were an inflow diameter of 30 mm, a cylinder length of 575 mm, an overflow diameter of 60 mm, an underflow diameter of 50 mm, a cylinder diameter of 335 mm and a cone angle of 68°. The low-pressure hydrocyclone was operated with a lower inlet pressure (average 1.38–5.56 kPa) that could be maintained under water level differences that ranged from 17.5 to 53.5 cm between the water surface of the feeding mass cylinder and the middle of the inlet pipe of the low-pressure hydrocyclone. By varying the inflow rate, underflow ratio and feed concentration, the separation performance of the low-pressure hydrocyclone was affected. The separation performances were determined from total separation efficiency and grade efficiency. Separation performances were determined according to the different inflow rates of 400, 600, 800 and 1000 ml s^{-1} and their respective underflow ratios that ranged from 5% to 30%. The maximum total separation efficiencies for each inflow rate were 41%, 46% and 46% at 400, 800 and 1000 ml s^{-1} inflow rates, respectively, and at underflow rates of 30% of the inflow rates. In addition, a total separation efficiency of 46% was employed at 600 ml s^{-1} of inflow rate and with an underflow rate of 25% its inflow rate. As the feed concentration increased from 25 to 150 mg l^{-1}, the separation performances were gradually decreased. For the fine particles ranging 1–200 μm, the grade efficiency was higher at the higher inflow rate (higher than 600 ml s^{-1}) and higher underflow rate. However, for the coarse particles ranging 400–700 μm, the grade efficiency was higher at the lower inflow rate (lower than 600 ml s^{-1}) and higher underflow rate. The cut-point (d_{50}) values ranged from 30 to 200 μm for a feed size range of 1–700 μm. The Response Surface Method (RSM) model predicted an optimum operating inflow rate and underflow ratio of 721 ml s^{-1} of inflow rate and 30%, respectively, for the low-pressure hydrocyclone at a maximum total separation efficiency. Based on these findings, further design and operating adaptation of low-pressure hydrocyclones used for fine solids removal in recirculating aquaculture systems is expected.

1. Introduction

To date, micro-drum screens have been utilized for most solid removal processes in aquaculture systems. Because the economically allowable mesh size was set upwards of 60 μm, fine particles still accumulate in culture systems (Cripps, 1995; Patterson et al., 2003; Pfeiffer et al., 2008), and much more energy is needed to remove the rest solids. With regard to the adverse effects of fine suspended solids on culture species (Liltved and Cripps, 1999; Muir, 1982) and culture systems (Cripps and Bergheim, 2000; Summerfelt and Penne, 2005), an effective fine particle removal separator that is operated with less energy expenditure could make a considerable impact. A centrifugal separation could be applicable for this purpose.

The hydrocyclone is an industrially important solids–liquid type of separation equipment. Although it is widely used in many fields and industries, the selection and design of hydrocyclones are still empirical and experience based (Chen et al., 2000). Moreover, a full description of their performance is very complex due to the effect of a large number of design and operating variables.

The separation performance of high-pressure hydrocyclones has been studied for heavy materials (>2 g cm^{-3}) and fine particles (<212 μm) (Hou et al., 1998; Patil and Rao, 1999; Tavares et al., 2002). Solid wastes in the recirculating aquaculture system (RAS) usually originate from feeds and are composed of organic matters with a low density and wide range of particle sizes (Lee, 2010). Their

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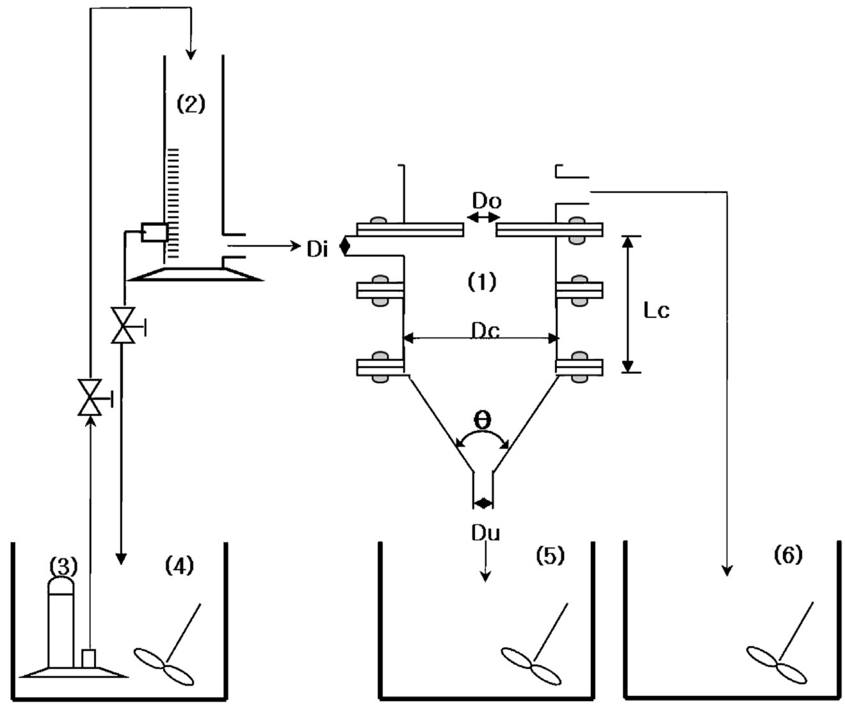

Fig. 1. Diagram of the experimental apparatus: (1) low-pressure hydrocyclone (Dc: cylinder diameter 335 mm, Lc: cylinder length 575 mm, Di: inflow diameter 30 mm, Do: overflow diameter 60 mm, Du: underflow diameter 50 mm, θ: cone angle 68°); (2) feeding mass cylinder; (3) pump; (4) feed resource tank; (5) underflow tank; and (6) overflow tank.

physical characteristics are clearly different from those of minerals, especially due to their low density and wide range of particle sizes from fractionation (Chen et al., 1993; Cripps, 1995; McMillan et al., 2003; Patterson et al., 2003).

Lee and Jo (2005a, 2005b) designed and suggested the optimum dimensions for a low-pressure hydrocyclone (LPH) that was tested for two sizes of polystyrene particles with similar densities and settling velocities to the feces of young common carp, *Cyprinus carpio*. Their waste production ultimately depends on the type and amount of feed provided (Summerfelt, 1998). The organic matter wastes from uneaten feed and feces can reach up to 23% of the total feed supplied and can have a large effect on total solids production (Lee et al., 2009). Moreover, the wide range of size and accumulation of fine particles make the process of solid waste removal more difficult (Chen et al., 2000; Lee, 2010; McMillan et al., 2003). The removal of fine organic particles in a recirculating aquaculture system is very important to reduce the accumulation of solids wastes in culture and biofilter systems that may impact fish health.

In centrifugal separation, performance depends on solid characteristics (particle size, particle density and feed concentration) and operating characteristics (inlet pressure and bypass underflow rate). The removal characteristics are quite conservative for solid and operating parameters. Thus, the dimensions of a centrifugal separator and its operating variations for specific fine solids are crucial data for the development and adoption of aquaculture systems and, specifically, recirculating aquaculture systems.

The major diameters of well-known hydrocyclones ranging 10–30 mm have been used commercially for more than 40 years (Petty and Parks, 2001). Coelho and Medronho (2001) used seven different diameters (15–122 mm) in their experiment that were thought to be wide enough to include most of the well-known hydrocyclone designs. The well-known hydrocyclones, such as Bradly (Antunes and Medronho, 1992), the Rietema (Medronho and Svarovsky, 1984), and the Krebs and Demco 4H models (Coelho and Medronho, 1992) operate with higher pressures and smaller dimensional scales. (Scott and Allard, 1983, 1984) presented the possibility of using hydrocyclones in conjunction with a microscreen filter as a pre-filter for aquaculture wastewater treatment. However, this system was also operated at high pressure. According to Wheaton (1977), an inlet pressure of 2500 × g was not unusual for operating a 300 mm diameter hydrocyclone, and hydrocyclones were typically evaluated with higher pressures that ranged from 50 to 150 kPa (Asomah and Napier-Munn, 1997). Rushton et al. (1996) also noticed that an inlet pressure of 800 × g (dia. 300 mm) and 50,000 × g (dia. 10 mm) was common for a hydrocyclone. Compared with the low-pressure hydrocyclone used in this experiment, these values are very high. The dimensions of the low-pressure hydrocyclone in the present study include a bigger cylinder diameter than those of the high-pressure hydrocyclones, and the hydrocyclone was operated at an inflow rate of 400 and 1000 ml s^{-1} that was introduced by an inlet pressure of 1.38–5.56 kPa. The overall design is intended to be operated at a much lower inlet pressure compared to commercial high-pressure hydrocyclones.

The aim of this study is to evaluate the separation performance of low-pressure hydrocyclones for fine organic particles by varying the system's operating parameters such as inflow rate, underflow rate, particle concentration and size distributions, and to suggest the optimum operating parameter values for the effective operation of a low-pressure hydrocyclone.

2. Materials and methods

2.1. Experimental equipment and procedure

Lee and Jo (2005b) designed the experimental equipment for the low-pressure hydrocyclone. Fig. 1 shows the diagram of the experimental system. The dimensions of low-pressure hydrocyclone used in this experiment are a cylinder diameter of 335 mm, a cylinder length of 575 mm, an inflow diameter of 30 mm, an overflow diameter of 60 mm and an underflow diameter of 50 mm. The experimental set-up has a 1000 L water capacity feed resource