Aquacultural Engineering 61 (2014) 1–8

Contents lists available at ScienceDirect

Aquacultural Engineering

journal homepage: www.elsevier.com/locate/aqua-online

Performance evaluation and engineering considerations for a modular- and culvert-based paddlewheel circulator for split-pond systems

Jeonghwan Park[a,*], David Heikes[b], Matt Recsetar[a], Luke A. Roy[a]

[a] Department of Aquaculture and Fisheries, University of Arkansas at Pine Bluff, Pine Bluff, AR 71601, USA
[b] Dunn's Fish Farms, Inc., Brinkley, AR 72108, USA

ARTICLE INFO

Article history:
Received 8 December 2013
Accepted 13 May 2014

Keywords:
Split-pond system (SPS)
Paddlewheel circulator
Power requirement
Water flow rate
Drag force

ABSTRACT

The split-pond system (SPS) has been proposed as an alternative culture method to increase the efficiency of pond aquaculture production. This study evaluated the performance and the engineering models of paddlewheel circulators on commercial catfish SPSs.

The power requirement and the water flow rate by the circulators increased as the rotational speed and water depth in the culvert increased. The rotational speed increased the power requirement exponentially and the water flow rate linearly, while the water depth, which determined the wetted surface area of paddles, increased both linearly. Increasing the rotational speed decreased relative pumping efficiency relative to power used. Under the given field operational conditions, the predicted power requirement appropriately corresponded with the measured power requirement and the predicted values were within 95% of measured values. Good agreement was also noted between measured and predicted water flow rates, and the predicted values were 91.4% of the measured values.

Based on the models developed, it was projected that increasing the wetted surface area of paddles is more energy efficient than increasing the rotational speed and minimizes mechanical failure due to high torque. However, the power requirement was also projected to increase with increasing wetted surface area at a certain threshold, as attempts to decrease the rotational speed were made to achieve a target water flow rate.

Published by Elsevier B.V.

1. Introduction

Since traditional earthen ponds have been devoted to aquaculture production, channel catfish (*Ictalurus punctatus*) has accounted for the largest portion of US aquaculture production (Kaliba et al., 2007). Since the early 1970s, efforts to intensify pond aquaculture have enhanced productivity of pond culture and sustained its business feasibility (McDonnell, 2012). In the US, rising production costs and competition with foreign countries have negatively impacted business revenues and total water surface area for production has declined substantially since 2008 (USDA, 2012). As a result of these challenges, demand for innovations to improve production efficiency in pond aquaculture has increased (Bastola and Engle, 2012).

To increase the efficiency of pond aquaculture, the split-pond system (SPS) has been proposed as a solution to the limitations of oxygen supplementation and waste treatment in static ponds (McDonnell, 2012). The SPS was originally designed by researchers at Mississippi State University (Tucker and Kingsbury, 2010) by drawing from advantages of the partitioned aquaculture system (PAS) of Clemson University. The PAS is reported to enhance catfish production by 4–6 times compared to conventional earthen ponds (Brune et al., 2004, 2012). Currently, there are over 550 ha of split-pond production systems in Mississippi, Arkansas, and Alabama devoted exclusively to catfish culture, primarily hybrid catfish (Travis Brown, United States Department of Agriculture Agricultural Research Service, Stoneville, MS, personal communication). With the success experienced by many farmers utilizing the SPS it is gaining popularity and more traditional ponds are being modified into SPS.

The SPS consists of two uneven sections divided by an earthen levee, and confines fish in a small section that comprises 15–20% of the total pond area. The remaining area (80–85% of the total pond area) serves as a large algal growth basin that provides oxygen production and waste treatment. These two pond sections are connected by two water pathways, and water between the two

* Corresponding author. Tel.: +1 870 575 8128; fax: +1 870 575 4639.
E-mail address: jpark@uaex.edu (J. Park).

http://dx.doi.org/10.1016/j.aquaeng.2014.05.002
0144-8609/Published by Elsevier B.V.

sections is actively circulated by a circulator when oxygen levels are adequate. Water exits the fish basin through one pathway and flows back to the fish basin by the circulator through the other pathway, following a residence time in the algal basin. During the daytime, water is exchanged to remove wastes and replenish oxygen in the fish basin through the algal basin. Circulation is stopped at night, and paddlewheel aerators are run to supply oxygen only into the fish basin. Confinement of fish to the small basin allows for efficient aeration compared to traditional ponds. It also allows farmers to feed and harvest fish more efficiently, increasing production and revenues.

Due to a relatively modest construction investment, convenience in retrofitting existing earthen ponds and ease of operation (McDonnell, 2012), the SPS is being recognized by commercial catfish farmers as an alternative culture method to maximize production of fish while allowing for better culture management in ponds. McDonnell (2012) has evaluated the performance of a SPS and provided a better understanding of water quality and nutrient dynamics in the SPS. Brown and Tucker (2013) provided practical understanding in designing a slow turning paddlewheel circulator. Currently, there is still little information available regarding the performance efficiency of paddlewheel type circulators. The primary benefits of the SPS compared to traditional earthen ponds are from water circulation and mixing. Most circulators developed have been designed with insufficient engineering information and the performance of circulators in SPS has not been examined systematically in applied field trials on commercial fish farms. The performance and efficiency of circulators varies according to operational parameters such as rotational speed, and submergence depth of paddles (wetted surface area of paddles). Optimizing the terms of power consumption and water flow rate would minimize the energy cost of pond circulation and mechanical failure and maximize water pumping efficiency. The paddlewheel circulator used in this study was designed in the fashion of a modular and culvert-based paddlewheel circulator. This particular model is easy to transport, assemble, and install. It also minimizes construction investment compared to an oversized paddlewheel circulator and supporting structures. The objectives of this study were: (1) to gather performance information of the modular- and culvert based paddlewheel circulators installed on commercial farms, and (2) to establish engineering models and design considerations for further refinement and optimization of the paddlewheel type circulators.

2. Materials and methods

2.1. Dimensions and manufacture of the paddlewheel circulator

The circulator had eight paddles, consisting of seven wooden blades each (Fig. 1). The wooden blades were fastened to galvanized square tubing (5.08 cm) and designed to be bolted to a central hub to allow for easy field installation. A solid keyed shaft (6.19 cm in diameter) was coupled to the center of the central hub with SF series bushings and weld-on hubs. Seven wooden blades (1.52 m long × 15.2 cm wide × 2.54 cm thick) were placed over the edge of each paddle, covering the width of paddle. In order to reinforce the paddle and overcome the drag force that results from the rotating motion of the paddle through the water, struts were bolted between the paddles on both sides of the paddle frames. The paddlewheel circulators were equipped with either a 5-hp or a 7.5-hp AC electric motor (three-phase and 480 V) with a rotational speed of 1750 rpm. The 5 hp motors were connected to a gear box (model # 305L3 220NPC N210TC, Bonfiglioli, Hebron, KY) that directly reduced the shaft rotational speed to 7.8 rpm. The 7.5 hp units were connected to a gear box (model # 306L3 228NPC N210TC, Bonfiglioli, Hebron, KY) resulting in a reduced rotational speed of 7.35 rpm.

Fig. 1. The modular- and culvert based paddlewheel water circulator used in commercial split-pond systems.

A variable frequency drive was installed to allow for further control of paddlewheel rotational speed.

Two corrugated galvanized metal culverts (1.52 m diameter, 7.62 cm pitch × 2.54 cm rise, and spiral corrugation) were installed through a levee dividing each pond into two sections (20% fish basin; 80% water treatment basin, Fig. 2). A culvert (6.1 m in length) was attached to the paddlewheel device and the other culvert (9.1 m in length) was used for the return water flow. PVC coated wire mesh fish barriers were installed to prevent the escape of fish from both inflow and outflow culverts of the fish basin. Two units were equipped with rectangular mesh (1.27 cm × 2.54 cm) and the remaining units were equipped with square mesh (1.91 cm × 1.91 cm).

2.2. Data collection

Intensive field data was collected from 12 SPSs (1.8–.5 ha SPSs) on two commercial catfish farms in Arkansas. A total of 70 measurements were obtained during the production period from July, 2012 to July, 2013. Due to the difficulty of testing different rotational speeds and submergence depths of the paddle *in situ* on commercial farms, data was collected as natural changes of water depth and rotational speed of the paddle occurred during the ordinary management regimes of each farm.

2.2.1. Power consumption and water flow measurement

The power requirement of circulators was calculated by measuring amperage with a digital ammeter (ACD-10PLUS, Amprobe, Everett, WA) and the following equation for a 3 phase motor.

$$P_m = \sqrt{3} \times PF \times I \times V/1000 \quad (1)$$

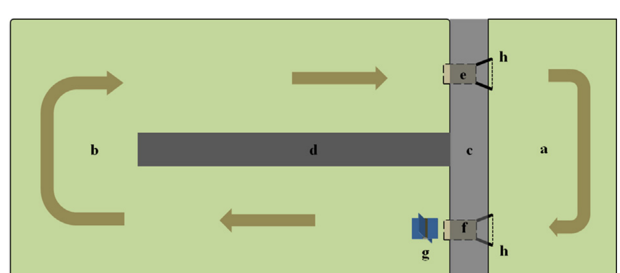

Fig. 2. The schematic diagram of split-pond systems ((a) fish basin, (b) water treatment basin, (c) and (d) earthen levee, (e) and (f) spiral underground culverts, (g) paddlewheel circulator, (h) wing walls and metal screens; arrows indicate the direction of water flow).