Aquacultural Engineering 64 (2015) 25–31

Contents lists available at ScienceDirect

Aquacultural Engineering

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

Visualisation of the wake behind fish farming sea cages

Heini Winthereig Rasmussen*, Øystein Patursson, Knud Simonsen

Aquaculture Research Station of the Faroes, Við Áir, FO-430 Hvalvík, Faroe Islands

ARTICLE INFO

Article history:
Received 30 June 2014
Accepted 10 December 2014
Available online 24 December 2014

Keywords:
Aquaculture
Full scale experiments
3-D visualisation
ADCP
Velocity reduction

ABSTRACT

Boat-mounted Acoustic Doppler Current Profiler (ADCP) measurements were conducted at a full scale salmon farm outside Tórshavn, Faroe Islands. Measurements were conducted over the duration of two days in an oscillating tidal current. The objective was to visualise the flow field in the wake of the salmon farm and make predictions of the velocity reduction from the farm equipment, i.e. cage nets primarily. Kriging was used to interpolate results from measured velocity to a 3-dimensional (3-D) volume of water, including bathymetry data from the farm site. Results indicate that it is possible to visualise the flow field and make prediction of the velocity reduction. Comparison is made with theoretical velocity reduction and there is good agreement with only a 5% difference in the minimum velocity magnitude.

1. Introduction

In Aquaculture, it is crucial to have a good understanding of the flow in and around sea cages. Fish health is dependent on sufficient water exchange in maintaining an acceptable environment inside the cage by supplying dissolved oxygen and removing waste. However, water exchange can also introduce parasites, such as sea lice and amoeba, to the cage environment. Salmon farms predominantly consist of several sea cages in a grid formation. When choosing how to position the grid at a potential farm site, one has to consider how the wake from a cage will affect other cages downstream.

Several studies have investigated the hydrodynamics of nets. Løland (1991) presented a formula for calculating a flow reduction factor by means of the drag coefficient (C_d) of the net panel. This was derived from a source model and validated by tow tank experiments on nets of different solidity and at different towing speeds. Løland (1991) also derived a formula for calculating a net drag coefficient by means of the net solidity. Tow tank experiments on a scaled model cage were performed by Patursson (2008) and the velocity reduction through the centre line agreed well with Løland (1991).

With the introduction of porous media as a substitute for nets in Computational Fluid Dynamics (CFD) simulation, Patursson et al. (2010) has made it possible to do CFD simulation of the flow through and around a sea cage (Patursson, 2008; Zhao et al., 2013; Bi et al., 2014). Bi et al. (2014) combined this procedure with a lumped-mass mechanical model, which takes into consideration the fluid-structure interaction between the flow and the net. With this method, Bi et al. (2014) performed a CFD simulation of flow through 4 cages with about 50% velocity reduction behind the last cage.

Both in experimental scaled cage model tests (Patursson, 2008; Huang et al., 2006) and in porous media CFD simulations (Patursson, 2008; Patursson et al., 2010), concerns have been raised about the net simplifications. In scaled cage model experiments it is not possible to scale the nets by the same ratio as the cage diameter. Most common practice has been to scale the nets in order to conserve the Reynolds number (Patursson, 2008). However, there are concerns that this approach may not reproduce the correct velocity reduction. As mentioned above, the net is substituted by a porous media in CFD simulations and it is unclear if this resolves secondary flow features.

Although a lot of CFD simulations and some scaled cage model experiments have been done on the topic (Patursson, 2008; Patursson et al., 2010; Zhao et al., 2013; Bi et al., 2014, 2014, 2013; Huang et al., 2006), there are very few full scale measurement results to compare with (DeCew et al., 2013; Lader et al., 2008). Therefore, there is a need for more full scale experiments to validate the CFD simulation methodology. Full scale experiments have been difficult to perform due to the scale of the cage system and the complexity of the sea environment.

Jamieson et al. (2011) visualised the 3-D flow around a submerged wing dike in the Missouri river. It involved boat-mounted

* Corresponding author. Present address: Aquaculture Research Station of the Faroes, Faroe Islands. Tel.: +298 474747.
E-mail address: heini@fiskaaling.fo (H.W. Rasmussen).
URL: http://www.fiskaaling.fo (H.W. Rasmussen).

http://dx.doi.org/10.1016/j.aquaeng.2014.12.001
0144-8609/

ADCP to conduct measurement transects and interpolating the results to a 3-D volume. Their experiment was done in a steady current. In Section 3 it is suggested to extend this approach to be applicable to tidal flow as well by adding a method for normalising the measured flow velocities to visualise the 3-D flow field behind ocean fish farming cages of the gravity type. The field experiment was conducted at the salmon farm site Gulin in the Faroe Islands. The current measurements were performed in the time period of 8–9th May 2012.

2. Data

2.1. Location and tidal current conditions

The experiment location was in the fjord of Nólsoy, more specifically at the salmon farm located in the bay of Tórshavn, just outside of the capital of the Faroe Islands, Tórshavn. The fjord is characterised by a relatively deep trench with depths down to 105 m in the middle, flanked by plateaus at 30–50 m depth on both sides (Fig. 1). The experiment site is located on a plateau West of the fjord trench. The tidal current in Nólsoyarfjord runs north for 4 h and south for 8 h to complete one tidal cycle. This is atypical for tidal currents in the Faroes, where semi diurnal tides are predominate. The tidal current in the fjord produces a recirculation area in the bay, due to the bathymetry of this bay and its position in respect to the fjord. This ensures water exchange at the farm site. This back-eddy rotates clockwise, while the tidal current runs south through the fjord, and anti-clockwise when it runs north.

2.2. Fish farm layout

The salmon farm consisted of 10 sea cages of the gravity type, placed in a 2×5 grid anchored approximately parallel to the shore (Fig. 1). Two cages were 160 m in circumference, while the remaining 8 were 128 m, which equates to diameters of approximately 50 m (D) and 40 m (d), respectively. The row of cages closest to the shore (inner row) consisted solely of 128 m cages. The outer row, that is the row of cages furthest from shore, consists of three 128 m cages flanked by two 160 m cages. The sea cages had vertical net sides and a conical net bottom. The net side stands 13 m while the depth at the cage centre was 22 m. The nets had a net mesh size of 22 mm and a twine thickness of 2.4 mm.

2.3. Bathymetry data

Bathymetry data (Fig. 1) at the farm site, is from near shore measurements originally performed by the Office of Public Works in the Faroes (http://www.landsverk.fo). The original bathymetry data had a resolution of 20×20 m. Three bathymetry data sets were created by interpolating the original bathymetry data. The resolution of the three other bathymetry data sets were: 1×1 m, 2.5×2.5 m and 5×5 m. Interpolation of the original bathymetry data was necessary in order to produce 3-D interpolation grids of different resolutions. The effects of different resolutions are described in Section 3.2. Directly beneath the fish farm cages, the bottom has a moderate slope from about 20 m to about 30 m going perpendicular to the long side of the cage formation. This corresponds to approximately a 4° degree slope. In the wake to the south-east of the cages, the bottom becomes increasingly deeper with an increasing slope. The slope is steeper with approximately 22° declination until it reaches a plateau at about 40 m depth. The bed material consists primarily of bed rock, where some seaweed may be present.

2.4. Boat mounted ADCP velocity data

The water velocity measurements where performed with a boat mounted ADCP. The ADCP was a RD Instruments (RDI) Workhorse Sentinel 300 KHz with Bottom Track (BT). The ADCP was configured with 4 m bins and a sampling rate of 1 Hz. Blanking distance was 3.63 m including the depth of the transducer head, which was 0.5 m below the surface. There was no overlapping of bins. The measurement error of the ADCP was ±3.6 cm/s with these settings (RD Instruments, 2014). The commercial software WinRiver II was used for collecting and managing transects. BT was used as reference for both water velocity and boat speed. The average boat speed was about 0.5 m/s. This gives an ensemble space of about 0.5 m. Measurement position where logged with a Garmin etrex vista GPS. By using DGPS the accuracy was ±5 m. The GPS coordinates where acquired sequential with the ADCP measurements. The ADCP was directly linked to a laptop to see flow measurement instantaneously.

A Rubber Buoyancy Boat (RBB) was used, as it is completely made of rubber and therefore not magnetic in itself. This is an advantage, as it will not interfere with the ADCP internal compass and produce a faulty flow direction. The only thing on the boat that could affect the ADCP's compass, was the out-board engine. The ADCP was placed at the bow of the RBB, as far away from the engine as possible. All collected heading data were corrected relative to true north. The magnetic declination was −6.4° at the experiment site, during the measurements.

Measurements were performed by sailing in a path perpendicular to the current flow, downstream of the cages. In order to resolve the flow structure in the entire wake of the cages, the transect length was about 5 times the larger cage diameter (D) with the mid-point at the approximate centre of the width of the fish farm. This ensured capture of both the velocity reduction of the cages and the unobstructed free stream velocity flowing past the farm. 53 transects where collected at different distances from the cages ranging from $1.5\times D$ to about $13.5\times D$ (Fig. 1). The strong current created a slack in anchor lines in the wake of the cage frame. The slacked anchor lines where floating at the surface at an extent of about 60 m from the last row of cages. This prevented the boat in conducting measurements closer than $1.5\times D$ from the cages, as it was not possible to sail over the anchor lines.

2.5. Bottom mounted ADCP velocity data

Incoming tidal current velocity at the farm site was determined by a 2 MHz Nortek AquaDopp Current metre. The location of the AquaDopp is marked with a red dot (Fig. 1). The ping rate was 1 Hz, measured for 60 s every 8 min. The reported velocity is the average of each 60 s measurement period. The AquaDopp collected measurements at a depth of 6 m from the surface. The measurement uncertainty of a Nortek AquaDopp is 1% of the measured velocity (Nortek, 2013).

2.6. Theoretical velocity reduction

A theoretical expression for the non-dimensionalised velocity (u/U_0) behind a net panel, based on the solidity of the net (S), was derived by Løland (1991). It is based on a source-model and is uniform throughout the entire wake.

$$\frac{u}{U_0} = 1 - 0.46C_d \tag{1}$$

u is the flow velocity in the wake and U_0 is the free-stream velocity. It is calculated by means of C_d of the net. C_d is calculated from S as

$$C_d = 0.04 + (-0.04 + 0.33S + 6.54S^2 - 4.88S^3)\cos\alpha' \tag{2}$$