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Drag on and flow through the hydroid-fouled nets in currents

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ABSTRACT

Biofouling is an inevitable problem in marine aquaculture and it is prone to cause many negative effects on the hydrodynamic behavior of the aquaculture facility. In this study, the dominant biofouling on the netting of fish farms in the Yellow Sea of China was determined by field sampling. Plane nets with various levels of biofouling were obtained by submerging nets at different depths and for different durations. Drag acting on the biofouled nets in currents were investigated using laboratory experiment. The results indicate that drag acting on the net increases with increasing level of biofouling. Compared to the clean net, the accumulation of biofouling can lead to over 10 times more hydrodynamic load on nets. Flow fields around the biofouled nets were simulated using a porous-media fluid model which was validated by corresponding laboratory experiment. As the level of biofouling increases, the flow velocity downstream from the net decreases continuously. The net with the greatest level of biofouling produces the most serious shielding effect with 21.4% reduction in flow velocity. Using the proposed empirical equations, both the drag on and flow velocity downstream from a hydroid-fouled net can be predicted.

1. Introduction

With the steady growth of world population and the continuous improvement of living standards, the demands for high quality seafood continue to grow. To fulfill this goal, efforts must be paid to modern technology regarding to offshore aquaculture facilities and equipments. In the aquaculture industry, offshore net cages are becoming prevalent around the world. A typical net cage is mainly composed of floating collar, net chamber, weight system and mooring system. Similar to other marine structures, the infrastructure of the net cage suffers from the effects of biofouling in the open sea (see Fig. 1). Biofouling, the accumulation of marine organisms, is prone to leading to rapid occlusion of the netting mesh (Braithwaite et al., 2007), which may causes the following disadvantages: i) biofouling communities acting as disease reservoirs can increase disease risk to the farmed fish (Fitridge et al., 2012), ii) the hydrodynamic forces acting on the net cage are dramatically increased, which increases the risk of structural failure and fatigue damage of the net cage (Klebert et al., 2013), iii) the biofouled netting is easily deformed in currents and thus causes negative effect on the effective volume for the farmed fish and iv) the attenuation of currents through the net cage is increased, which decreases the water exchange and oxygen supply inside the net cage (Bi et al., 2015a). In addition, the motion responses, geometric deformation, dynamic forces as well as flow fields regarding to the net cage are important for both design and maintenance of offshore aquaculture facilities. Thus, the investigation on hydrodynamic characteristics of biofouled net has great significance for aquaculture engineering.

Over the past decades, a large number of studies have been carried out to investigate the hydrodynamic characteristics of the net structure and the net cage, see for example the review by Klebert et al. (2013). However, there is paucity of research into the effects of biofouling on the hydrodynamic characteristics of the net structure or the net cage. In the literature, Swift et al. (2006) performed experiments both in a tow tank and in the field to measure the drag forces acting on biofouled plane nets. Overall, drag force increased with both net solidity and volume of biofouling with considerable scatter, which was attributed to the different species of the biofouling. There are many different kinds of biofouling organisms related to the net cage, e.g., hydroid, mussel and algae, etc. (Bloecher et al., 2013). The physical and geometrical characteristics as well as the distribution of the biofouling take various forms and have different effects on the hydrodynamic characteristics of the net cage. Thus, a separation of biofouling types in future studies was suggested by Swift et al. (2006). In Norway, the leading producer of Atlantic salmon, the hydroid *Ectopleura larynx* dominates biofouling communities on coastal fish farms during the peak of the biofouling season (Guenther et al., 2010). Therefore, the biofouling of hydroid *Ectopleura larynx* on salmon cage nets has become an important concern for the Norwegian finfish industry. Gansel et al. (2012) conducted

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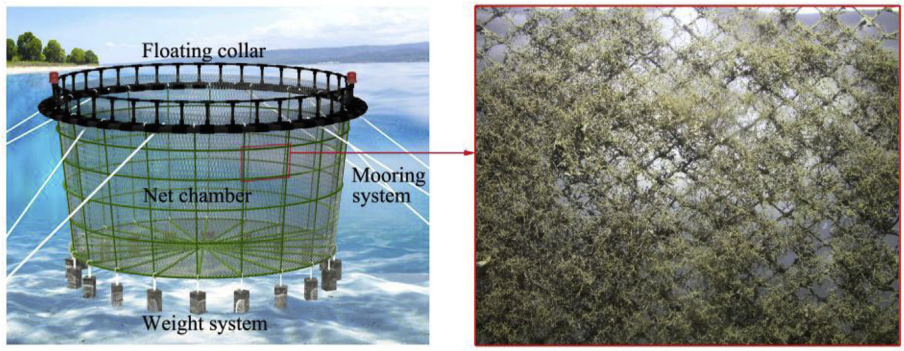

Fig. 1. Sketch of the net cage (left) and biofouled net (right).

physical-model tests on six cylindrical metal nettings using PIV technique to investigate the effect of porosity on the ventilation inside the cages and the vertical transports within the near wake. It was found that heavy biofouling of aquacultural netting can lead to internal circulation which may dramatically reduce the ventilation of the fish cage. Gansel et al. (2015) performed experimental study on both clean and fouled plane nets in a flume tank to evaluate the effect of hydroids, an important biofouling organism in Norwegian aquaculture, on the forces acting on nettings. The relationship between net solidity and drag force was assessed and a method was proposed to parameterize the effect of biofouling in terms of an increase in net solidity. Lader et al. (2015) performed field tests to investigate the growth characteristics of hydroids that grow on a net and conducted laboratory experiments to study the hydrodynamic drag on the fouled twines using fabricated models of net twines with artificial hydroid fouling. Finally, a curve fit showing the relationship among growth period, hydroid length and drag coefficient for different Reynolds numbers was made based on the measurements of the drag on twines with three different biofouling levels.

Although much progress has been made, to the best of our knowledge, the effects of biofouling on the hydrodynamic characteristics of nets have not been studied systematically. Technical standards, taking the Norwegian Standard NS9415 for example, regulating the use of structural elements of fish cages and farms, acknowledge an effect of the accumulation of biofouling on hydrodynamic loads acting on the net cages, but fail to describe the effect of biofouling in detail (Standard Norge, 2009; Gansel et al., 2015). Thus, it is essential to conduct researches into the hydrodynamic characteristics of the net cage in currents and waves considering the effect of biofouling. There are many different kinds of biofouling organisms, which is primarily depending on location and season, related to marine aquaculture. The physical and geometrical characteristics as well as the distribution of various types of biofouling have different effects on the hydrodynamic characteristics of the net cage. It is an urgent need to quantify the effect of biofouling organisms with various physical and geometrical characteristics on hydrodynamics of aquaculture nets. As a start, this study aims to characterize the drag effects and flow through the plane nets with different levels of hydroid which is the dominating fouling organism on fish farms in the Yellow Sea of China, which is expected to contribute to a better understanding of structural design and risk analysis of aquaculture net cages in the open sea.

2. Material and methods

Field sampling was firstly carried out to obtain the plane nets with various levels of biofouling. Then, laboratory experiments were conducted to study the hydrodynamic characteristics of biofouled nets in currents. A load cell was used to measure the forces on the plane nets with various levels of biofouling. The flow velocities around the plane nets were measured using an acoustic Doppler velocimeter (ADV). As the ADV can only monitor the flow velocities of some scattered positions, a numerical model was introduced to simulate the flow fields around the biofouled nets as an effective supplement.

2.1. Field sampling

The net used in this study was a 0.4 m × 0.4 m knotted polyamide net with 16 and 11 meshes in the horizontal and vertical directions, respectively. The twine diameter was 1.6 mm, and the length of mesh bar was 20.6 mm (see Fig. 2). Mounted as diamond meshes, the net solidity ratio is 0.151 calculated using the empirical formulae (Bi et al., 2013). In order to suppress net deformation, the plane net was stretched on a square steel frame with a 6 mm diameter.

To obtain the accumulation of biofouling at various depths, a plane-net assembly was designed comprising three plane nets with a center-to-center distance of 1 m between two adjacent plane nets (see Fig. 2). The top of the plane-net assembly was fixed to a floating platform at a fish farm located near Guanglu Island, Dalian, China. Three plane-net assemblies, 9 plane nets in total, were prepared to be deployed. The first plane-net assembly was deployed on 25 July 2016. The other two assemblies were deployed every two weeks. In this way, different levels of biofouling were expected to be obtained. All the plane nets were recovered and transported to the laboratory on 18 October 2016.

2.2. Laboratory experiment

2.2.1. Laboratory set-up

As indicated by Gansel et al. (2015), two techniques for drag measurements of the plane net are available: i) the net is placed in a tank large enough to avoid any wall effects and ii) the net spans almost the entire cross section of the tank. In this study, the biofouled plane net should be treated as a part of the whole net chamber of the net cage. Therefore, the second technique was chosen with little spacing, approximately 25 mm, between a plane net and tank walls; thus assuring almost all water to be pressed through the net.

The laboratory experiments were conducted in a two-dimensional wave-current tank at the State Key Laboratory of Coastal and Offshore Engineering (SLCOE), Dalian University of Technology, Dalian, China. The tank is 22 m long, 0.45 m wide and 0.6 m deep. The water depth was 0.45 m during this experiment. Both the bottom and side walls of the tank are made of smooth glass with negligible frictional drag.

Both clean and biofouled plane nets were tested in the tank. The plane nets were mounted with four symmetric equi-length bridle lines which were attached to a load cell upstream of the net (see Fig. 3). Two vertical bridle lines were arranged to maintain the plane net at a constant depth without imparting a horizontal force. The load cell was fixed by a vertical rod with a diameter of 10 mm (see Fig. 3). The horizontal distance between the rod and the plane net was 0.6 m, and thus the rod had no effect on the hydrodynamic characteristics of the plane net.