IMPACT OF MESH/TWINE RATIO ON THE WAKE OF SIMPLIFIED OCEANIC AQUACULTURE PEN

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We investigate the fundamental aspects of the impact of the mesh/twine ratio on the wake of a simplified aquaculture pen. For this purpose, 10 circular "pens" with mesh/twine ratio varying from 4.45 to 17.8 were manufactured. The resulting surface porosity is between 0.67 and 0.90, since typical aquaculture nets have a porosity of about 0.80. This porosity parameter, imposed by the size of the fish, plays a key role on the load applied by the currents to the structure. The experimental results acquired by Time-Resolved Particle Image Velocimetry (TR-PIV) show the impact of the geometry on the diffusivity of the flow as it goes through the pen as a function of the porosity. We have identified a parameter, based on the pen geometry that demonstrates a collapse of the flow velocity in the wake of the pens allowing us to establish a prediction criterion for the velocity magnitude in the wake of similar structures. As the porosity is reduced, the flow around the pen exhibits wake patterns similar to those of a solid circular body.

1 INTRODUCTION

The aquaculture industry is experiencing a period of dramatic expansion worldwide. Since the early 1980s there has been near exponential growth in the quantity of seafood being produced in this manner, and in the near future aquaculture will account for half of the world's global harvest of aquatic organisms[1]. With such growing demand, fish farms are rapidly multiplying, the pens are getting wider, deeper and are located further offshore. Inevitably, expansion creates environmental and industrial challenges. The waste produced in a pen is generally washed away with the tide, however with the increasing density of pens in fish farms, the pens tend to pollute one another. It has been recently identified that with the returning tide, a significant amount of the dissolved waste is able to return to the fish farm[2]. Further significant problems arise when higher loads are applied on the pen structures during storms or tides[3-4]. The numerical investigation by Zhao *et al.*[5] has demonstrated the impact on the inside velocity of multiple pens aligned in a flow. In order to optimize offshore fish farms based on simulations or prediction models, it is necessary to obtain a better understanding of the dynamics inside and around aquaculture pens. The present study focuses on the wake created by a simplified aquaculture pen modeled by a hollow porous cylinder of varying twine and mesh dimensions

2 EXPERIMENTAL SETUP

The experimental data were acquired using two flumes with different flow rate ranges. The first one is a recirculating flume with a low turbulence intensity of approximately 3%. Its cross-sectional area is 0.4 m x 0.4 m and the flow rate can vary from 0.015 m/s to 0.05 m/s. Based on the pen diameter, the resulting Reynolds number is 600 to 2000. This flume was used for PIV measurements and flow visualization studies. The second flume has a similar cross-section, 0.45 m x 0.50 m, but a greater flow rate, 0.10 m/s to 0.60 m/s. This flume was used solved for load cell measurements.

The PIV system consists of a 5W CW Nd: YVO4 laser from Spectra-Physics Millenia and a Basler A504k high frequency camera mounted with a Nikkor 20 mm, a Nikkor 50 mm or a Tokina 100 mm lens. The flow was analyzed by cross-correlating 50% overlapping windows of 32 × 32 pixels or 16 x 16 pixels, yielding fields of up to 160 × 128 vectors with a spatial resolution of 3.438 mm (0.086 *D*), 1.973 mm (0.0493 *D*) or 0.768 mm (0.0192 *D*) respectively.

Two different single point load cells were used to acquire the dynamic forces applied on the pen; (i) a KD78 0.5N load cell from ME-meßsysteme GmbH, offering a nominal force range of ± 0.5 N and measurements in the milliNewton range and (ii) a BBL-03 load cell from Celtron with a nominal range of ± 3 N.

The experimental pen models were manufactured using 3D-printing technology. This technology is able to guarantee a precision and regularity for the twines (*t*) and the mesh (*m*) of down to 20 µm (Fig. 1). The resulting surface porosity varies from $\varepsilon = 0.67$ to 0.90 and the porous holes are all square. Each pen, of constant diameter *D* and height *h*, is attached to a lid, itself attached to the load cell. The pen is placed at the center of the flume to avoid perturbations emanating from the boundary layer on the surfaces of the flume. For PIV data acquisition, a laser sheet is generated perpendicular to the pen axis, at $y = h/2$ (Fig. 1).

The Reynolds number characterizing the experiment is based on the pen diameter *D*, the upstream free flow U_{inf} and kinematic viscosity of water ν.

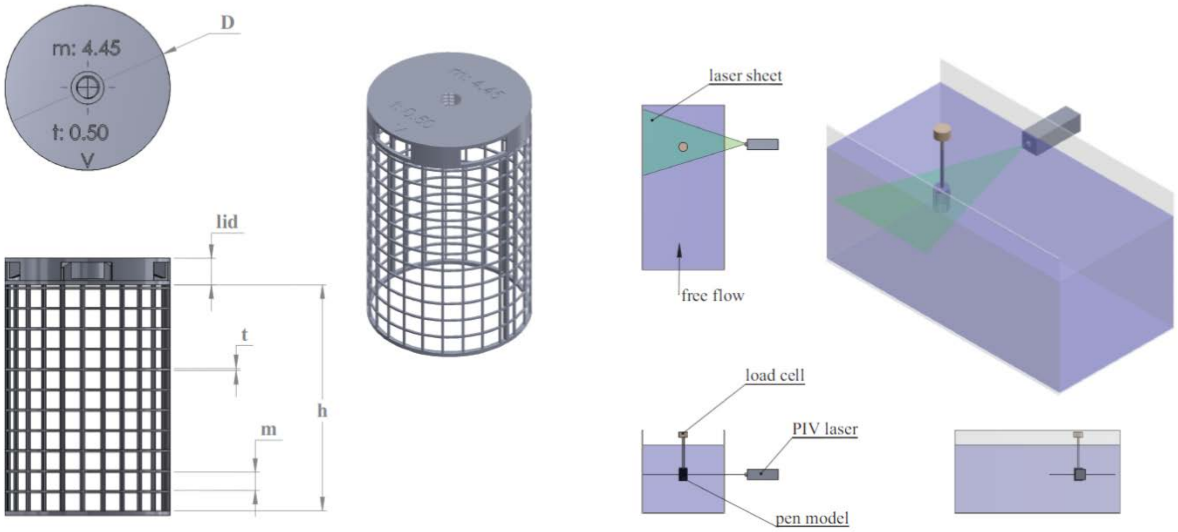

Figure 1. A schematic of a pen (left images) with the characteristic dimensions twine (*t*), mesh (*m*), diameter (*D*) highlighted; and a schematic of the flume setup comprising the PIV system, a load cell and the pen (right images).

3 RESULTS

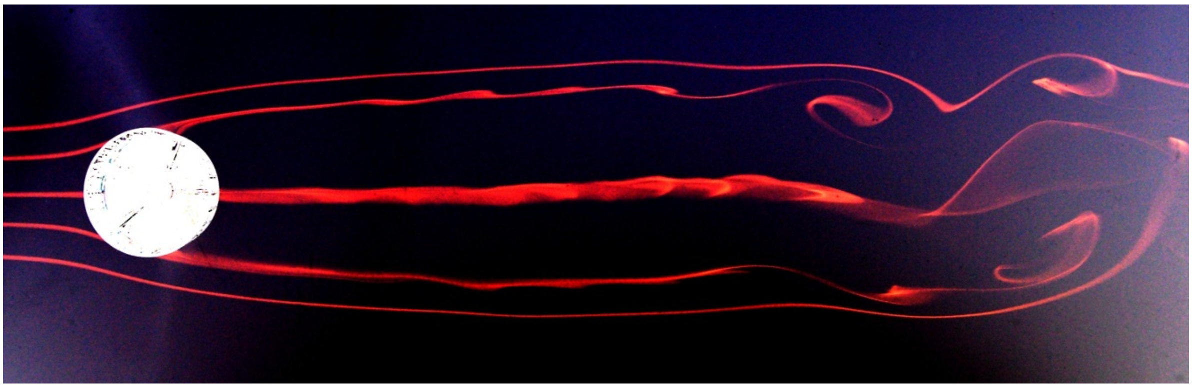

Figure 2. Instantaneous dye visualization of the flow through a pen; m = 4.45 mm, t = 0.75 mm, Re = 900.

Based on a series of dye visualizations made at Re = 900, we were able to identify the main flow through the aquaculture pen models (Fig. 2). Depending on the mesh/twine ratio, three different wake regimes were observed: (1) a totally penetrating flow where streamlines pass through the pen without any visible disturbances (2) a partially penetrating flow where some of the streamlines still go through the pen, but are reoriented toward the outside of the pen; in this case the wake doesn't present a recirculation zone, but what could be small Kelvin-Helmholtz instabilities developping, rolling-up an shedding into the wake (Fig. 2) and (3) a fully developed recirculation zone exhibiting a von Karman vortex street similar to that produced behind a solid cylinder[6].

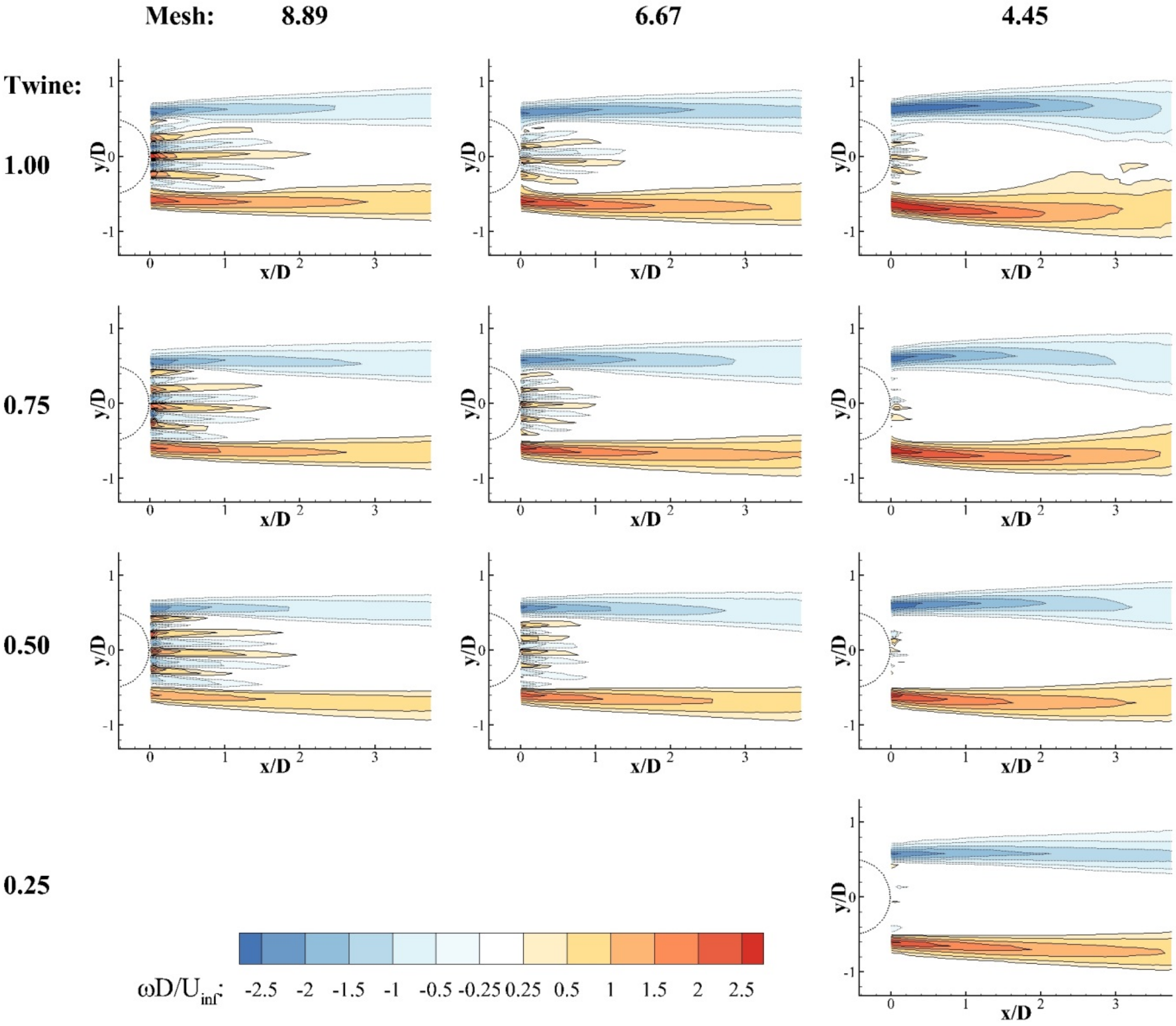

Figure 3. Contours of time averaged vorticity profile in the wake of 10 different pens. Re = 900.

The use of PIV allows us to gain access to a physical description and quantification of the flow past our model pens. The topology of the time averaged vorticity demonstrates how the twine and the mesh both have a direct impact on the vorticity generated by the structure (Fig. 3). If the spacing between two twines, sets by m, allows it each strand of twine (regardless of its thickness) creates positive and negative vorticity, just as would any similar bluff body. As seen in figure 3, at a constant twine thickness of 1 mm, the length of the wake past the twines is reduced by 35 % and 77 % as the mesh size is respectively reduced by 25% and 50 %. The same observation can be made for twines of thicknesses 0.75 mm and 0.50 mm. The wake of the twines appears to be dependent upon the mesh size, rather than the twine size. As the twine is reduced by 25 % and 50 %, the length of the wake is only reduced by 25 % to 35 % repsectively. We note that the twines generate a wake of up to 150t once forming a pen which is significantly more than in a solitary configuration.

Similarly as seen in the vorticity measurements, the time-averaged velocity in the wake varies from one pen to another. The velocity profile at two pen diameters from the rear of the pen shows a similar tendency to that found in the wake of a solid cylinder but with varying velocity minima (Fig. 4). In the case of the larger mesh, the influence of the twine is still noticeable on the averaged flow at $x/D = 2D$. The velocity profile in the direct wake of the pen, at $y/D \in [-0.5, 0.5]$ cannot be collapsed by the use of the porosity factor ε. Instead, a new parameter α based on the geometry is introduced, which is shown to collapse the data well.

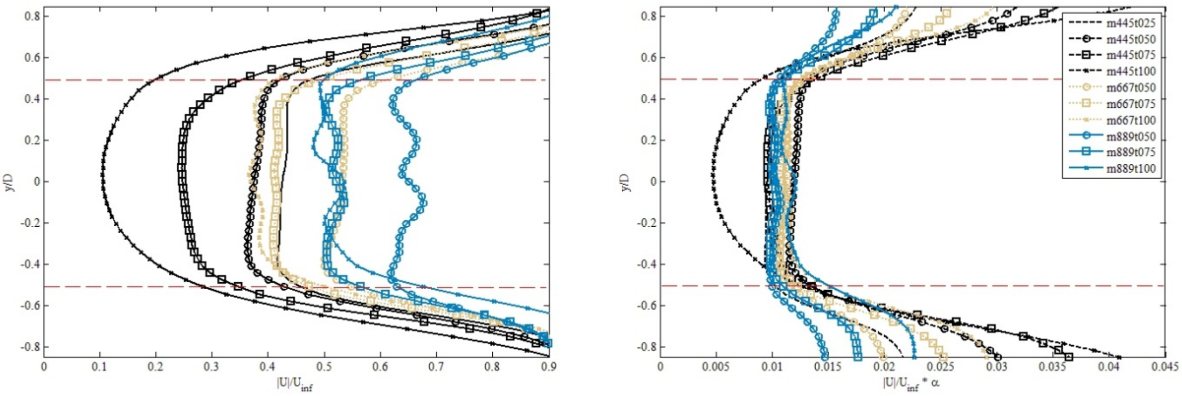

Figure 4. (left) Time averaged wake velocity profile at 2D from the rear of the pen; (right) Collapse of the time averaged velocity profile through the introduction of the geometry based coefficient α. Re = 900.

Depending on the twine/mesh ratio, the drag varies by a factor of two. However, the drag does not simply dependent upon the porosity of the pen, but is the result of a complex interaction between flow physics at two different scales. It is of interest to note that despite the pens being porous, and therefore having a reduced apparent solid surface compared to that of a solid cylinder, the drag force that they experience can be greater than a solid cylinder. Baselined against published results for a smooth solid cylinder, drag forces measured on the pens range from – 37 %, to + 20 %.

4 CONCLUSIONS

The presented study provides a better understanding of the flow near and through a porous structure similar to those used in the aquaculture industry. It provides the starting point from which optimal pen design strategies can be explored. By only varying one parameter, the twine or the mesh, the wake can exhibit three different types of flow dynamics, from nearly undisturbed laminar, to a classical von Karman street. For square holes in the pen, the size of the holes has more influence on the flow topology than the twine diameter. Nevertheless, it is only through a combination of these two parameters that the velocity profile can be collapsed, suggesting the possibility of an empirically-derived predictive law for the velocity in the wake of certain porous cylinders.

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