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ScienceDirect

Energy Procedia 85 (2016) 521 – 529

Energy Procedia

Sustainable Solutions for Energy and Environment, EENVIRO - YRC 2015, 18-20 November 2015, Bucharest, Romania

The influence of grooved surface and liquid properties on vortices formation in vicinity of immersed cylinders

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Abstract

The paper is dedicated to the experimental and numerical investigations of the viscous and viscoelastic flows around immersed cylinders with smooth and grooved surfaces. The study analyses the influences of the cylinders surface quality on the vortical structures and the wake developed downstream in a 2D open channel. The analyzed flow is in the domain of the free surface weakly turbulence regime under subcritical conditions. Numerical simulations are performed with turbulent solvers implemented in Ansys Fluent, using the VOF code for the calculation of the free surface geometry. The numerical results and visualizations are corroborated to determine the effect of the grooved surface on the drag coefficient and the location of the boundary layer separation points. The investigations emphasize also the qualitative changes of the flow spectrum induced by the Reynolds number magnitude and the presence of elasticity within the viscous fluid.

Peer-review under responsibility of the organizing committee EENVIRO 2015

Keywords: Free surface flow; numerical simulation; flow vizualizations; vortical structures

1. Introduction

The modelling of flow configuration around smooth and patterned cylinders is today a benchmark CFD domain of study in fluid mechanics, especially in relation to the boundary layer separation, wake formation and the laminar – turbulent transition [1-3].

The free surface flow around an immersed cylinder is a relatively novel subject of investigations. This particular motion, defined by two non-dimensional numbers: Reynolds and Froude, respectively

$$Re = \frac{\rho V_0 D}{\eta_0}, Fr = \frac{V_0}{\sqrt{gD}}, \quad (1)$$

is of interest for many applications from micro-fluidics to hydrology and geophysics, [1-5].

Peer-review under responsibility of the organizing committee EENVIRO 2015

doi:10.1016/j.egypro.2015.12.239

Sheridan et al. [6], was the first who investigated in details the kinematics of the flow pattern and the wake geometry downstream of the immersed cylinder, in particular the transport of vorticity flux from the free surface to the fluid domain. The experiments consisted of the velocity measurements (using the PIV technique) around the cylinder of diameter $D = 25.4$ mm immersed at different depth h in a free surface channel of width $B = 210$ mm and height at the entrance in the channel of $H_0 = 527$ mm. The ranges of Reynolds and Froude numbers were: $5990 < Re < 9120$, respectively $0.47 < Fr < 0.72$, which corresponded to an average upstream velocity within the range of $0.236 \le V_0 \le 0.359$ [m/s].

A direct visualization of the flow in vicinity of an immersed cylinder was presented and analyzed by Hoyt and Sellin [7]; the channel had dimensions of 102 mm width and 300 mm height, with D = 67 mm. The investigations were performed for six heights in the range $0 \le h/D \le 0.75$, but the study was focused only on three values, $h/D = 0;\ 0.3; 0.75$, at the same upstream average velocity, $V_0 = 0.43$ m/s.

Babu and Mahesh [8], studied the numerical simulations of the flow past cactus-shaped cylinders in the laminar regime (Reynolds numbers up to 300). The presence of grooved surface on cylinders reduce the viscous forces in comparison to a smooth cylinder for the same Reynolds number. At low Reynolds numbers the grooves create local recirculation zones, these regions have decreased surface stresses and decreased pressure forces closer to the surface. The phenomena of the decreasing drag induced by the grooves of the immersed bodies were later investigated by other authors, [2, 3, 9 - 11].

In a previous study, Tanase et al. [12], focused the analysis of the flow to the study of the interaction between the free surface and the cylinder's downstream wake, correlated with the influence of the immersed depth on the free surface geometry.

One aim of the present study is to establish the most indicated turbulence model to compute and to reproduce the flow pattern in the vicinity of an immersed cylinder for the weak turbulent subcritical flow regime, i.e. $Re < 10000$ and $Fr < 1$. Numerical simulations were performed with different turbulence solvers implemented in the Fluent code for the case of a smooth cylinder immersed in a 2D channel, the free surface geometry being computed using the VOF model. The numerical results are compared and calibrated with experiments performed with two fluids: water and weakly elastic polymer solution (small concentration of polyacrylamide in water – PAA).

The main goal of the paper is to investigate the influences of the grooved surfaces and fluids properties on the vortices formation downstream the immersed cylinders and on the location of the boundary layer detachment from the cylinders.

Nomenclature

D	diameter of the cylinder (m)
V_0	average velocity upstream the immersed cylinder (m/s)
ρ	density of fluids (kg/m^3)
η_0	viscosity of fluids (Pa·s)
g	gravitational acceleration (m/s^2)
Re	Reynolds number (-)
Fr	Froude number (-)
B	width of channel (m)
H_0	height at the entrance in the channel (m)
Q	flow rate (m^3/s)

2. Experimental set up

The experiments are performed in an open channel, the flow rate and the fluid height upstream the smooth and grooved immersed cylinders being controlled by a weir. The average velocity upstream the cylinders of diameter $D = 50$ mm is $V_0 = Q/BH_0$, where the flow rate Q is measured by volumetric method and height $H_0 = 105$ mm is kept constant, see Fig. 1. The grooved cylinder and the detail of the grooves geometry are presented in the Fig. 2.