23rd International Conference
ENGINEERING MECHANICS 2017
Svratka, Czech Republic, 15 – 18 May 2017

AN INVESTIGATION OF MASS TRANSFER IN A VORTEX SHEDDING PAST SQUARE CYLINDER

T. Kořínek*, M. Petříková**

Abstract: *This work investigates mass transfer in a vortex shedding past a square cylinder. The investigation is done by numerical simulations and an experiment on a hydrodynamic table. Turbulence is modeled by Large Eddy Simulation method. Investigated range of Reynolds numbers (Re) is Re = 6 600 - 20 000 for numerical simulations and Re =1 000 - 2 000 for the experiment. Obtained results indicate influence of Re on a distribution of an additional fluid in flow, where the leading edge of the square cylinder had a significant effect to the mass transfer in the spanwise direction.*

Keywords: CFD, Turbulent flow, Large Eddy Simulation, Mass transfer.

1. Introduction

There are a lot of engineering applications, where flow is influenced by surrounding bodies. Flow over a square cylinder was many times numerically and experimentally studied (Bouris et al., 1999, Davidson et al., 2000; Lyn, 1995). It is well known, that vortex shedding has a significant effect on heat and mass transfer past bluff body (Abbasi, 2003). Investigations of flow past cylinder were due to various Reynolds number, different attack angle etc. In case of heat transfer, there were done a lot of works. But in case of mass transfer, it was significantly smaller (Bošković-Vragolović et al., 2013). A typical investigated case in mass transfer is flow over obstacles, which represent air pollutions dispersion in an urban area (Rigas et al., 2004).

Main aim of this work was on spreading of additional fluid past square cylinder. The vortex shedding served to achieve uniform concentration profile in shorter distance comparing with a simple channel. This phenomenon was primary investigated using numerical simulations. There were used experimental data from the ERCOFTAC database (Lyn, 1995) to validate numerical simulations. The validation consisted from comparing mean streamwise velocities obtained by numerical simulations and by measurements.

2. Methods

An investigated domain was a simple channel with one vertically placed square cylinder. The domain with dimensions is shown in Fig. 1. The characteristic length D was 10 mm. The Reynolds number was calculated using the formula:

$$Re = \frac{u_\infty D}{\nu} \tag{1}$$

Where u_∞ is mean velocity on inlet and ν is kinematic viscosity. Three moderate Reynolds numbers were investigated only numerically Re_1 = 6 600, Re_2 = 13 300, Re_3 = 20 000. Lower Reynolds numbers were investigated experimentally. The variation of Reynolds numbers was achieved by changing initial velocity.

* Ing. Tomas Korinek: Department of Power Engineering Equipment, Faculty of Mechanical Engineering, Technical University of Liberec, Studentska 2; 461 17, Liberec; CZ, tomas.korinek@tul.cz

** Ing. Marketa Petrikova, PhD.: Department of Power Engineering Equipment, Faculty of Mechanical Engineering, Technical University of Liberec, Studentska 2; 461 17, Liberec; CZ, marketa.petrikova@tul.cz

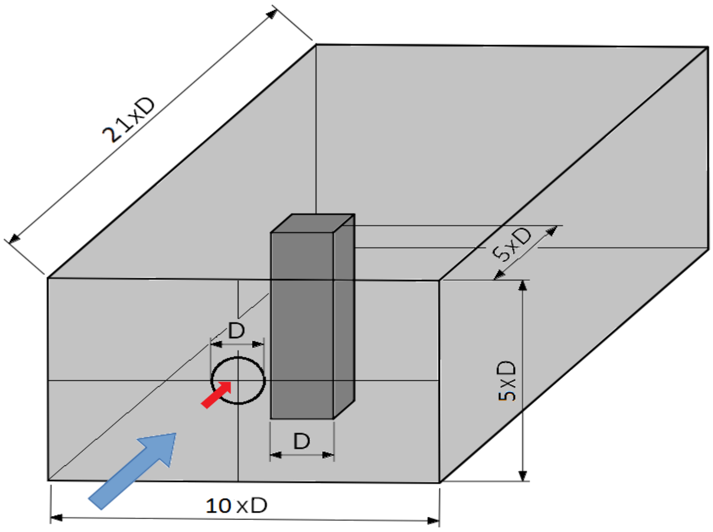


Fig. 1: Domain.

2.1. Numerical setup

The mathematical model was simplified for incompressible, isothermal flow of two fluid mixture and contained continuity equation, momentum equation and species transport equation.

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho u) = 0 \tag{2}$$

$$\frac{\partial}{\partial t}(\rho u) + \nabla \cdot (\rho u u) = -\nabla p + \nabla \tau \tag{3}$$

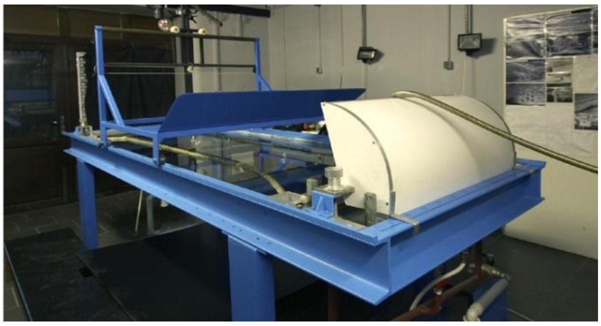
$$\frac{\partial}{\partial t}(\rho Y) + \nabla \cdot (\rho u Y) = -\nabla J \tag{4}$$

Where J is diffusion mass flux, p is pressure, u is velocity, ρ is density of mixture.

The computational grid was created with 3.6 million of cells for 3D and 52 400 cells for 2D. The number of elements on square cylinder in streamwise and crosswise direction was 45. There were created two additional grids for a test of mesh resolution. The first contained 2.5 million of cells and the second 1.8 million of cells. Special attention was given on a creating fine boundary layer with y^+ value bellow 1. This was due to use the Large Eddy Simulation (LES) method to solve turbulence. Numerical simulations were carried out by open source software OpenFOAM 4.1.

2.2. Experimental setup

In spite of the fact, that experiment is primary used for the validation of mathematical models, in this case served as an alternative method to the observation of mass transfer past bluff bodies. The experiment was simplified to 2D solution and was done on a hydrodynamic table shown in Fig. 2 left. Flow was visualized by aluminum particles with size 35 μm. A capture from the experiment with inverted colors is shown in Fig. 2 right.



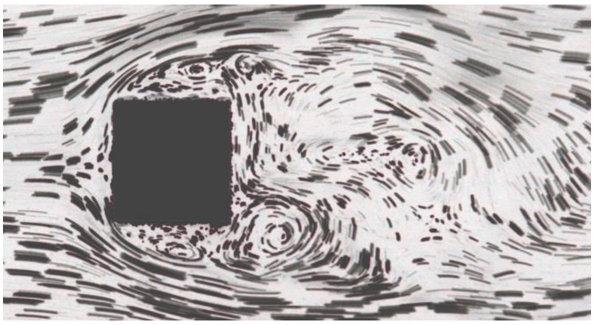


Fig. 2: Hydrodynamic table (left), a capture from experiment (right).

3. Results

The influence of Reynolds number to the mean concentration past square cylinder is shown in Fig. 3 for crosswise direction and in Fig. 4 for spanwise direction. There are shown four downstream transverse cross sections. The spreading of the additional gas is decreasing with increase of the Reynolds number. As it is shown in Fig. 3, there was a significant mass transfer in the crosswise direction. However the mass transfer in spanwise direction was also considerable, which is shown on chart in Fig. 4.

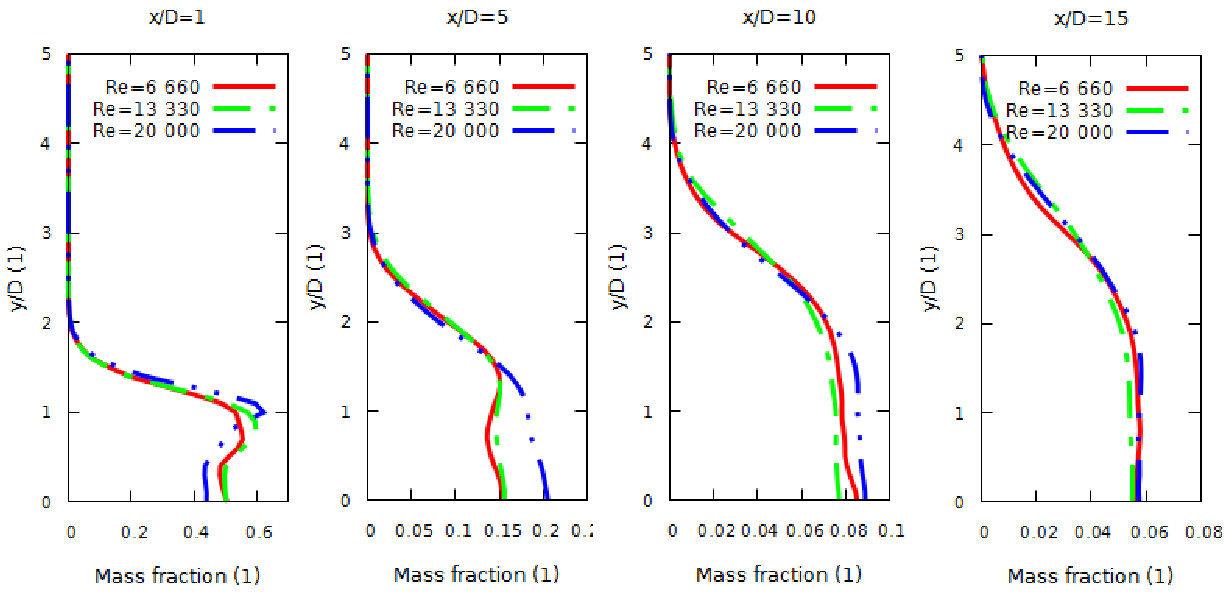


Fig. 3: Mean mass fraction profile in crosswise direction.

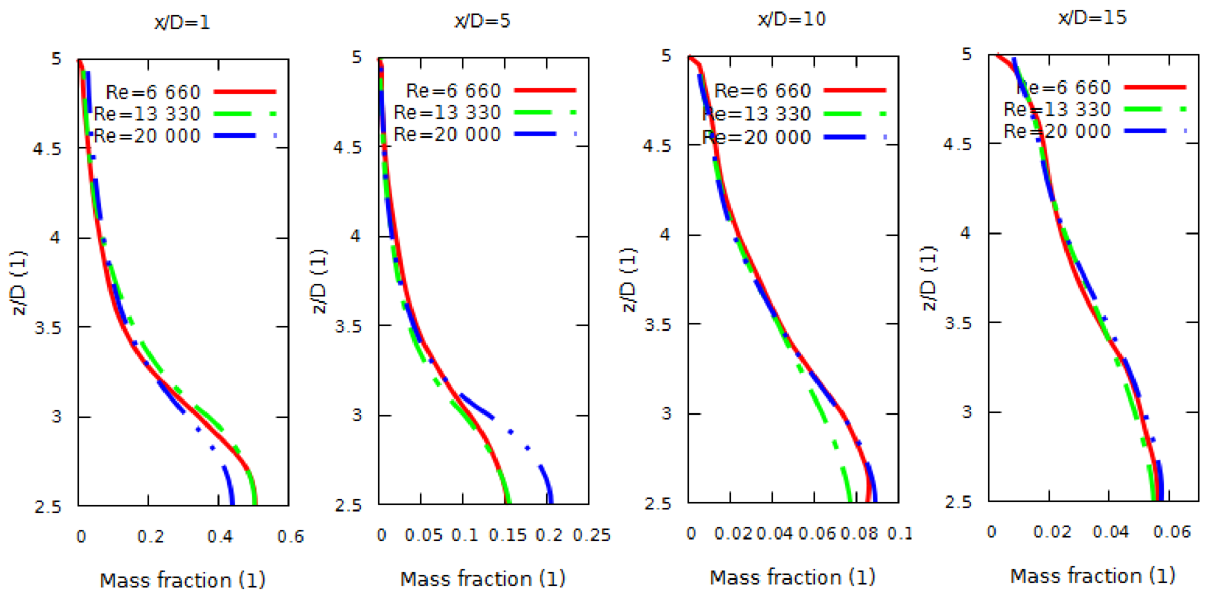


Fig. 4: Mean mass fraction profile in spanwise direction.

One of the methods for observation of mass transfer is using isosurfaces of mass fraction. The isosurface of mass fraction Y = 0.05 is shown in Fig. 5. There was a significant accumulation of mass behind the leading edge of the square cylinder. This occurred below and above the mainstream of the additional gas on both side of the cylinder. This accumulation was due to vortices formed behind the leading edge. The accumulated mass was periodically released and it led to more intense spreading of the additional gas in the spanwise direction.

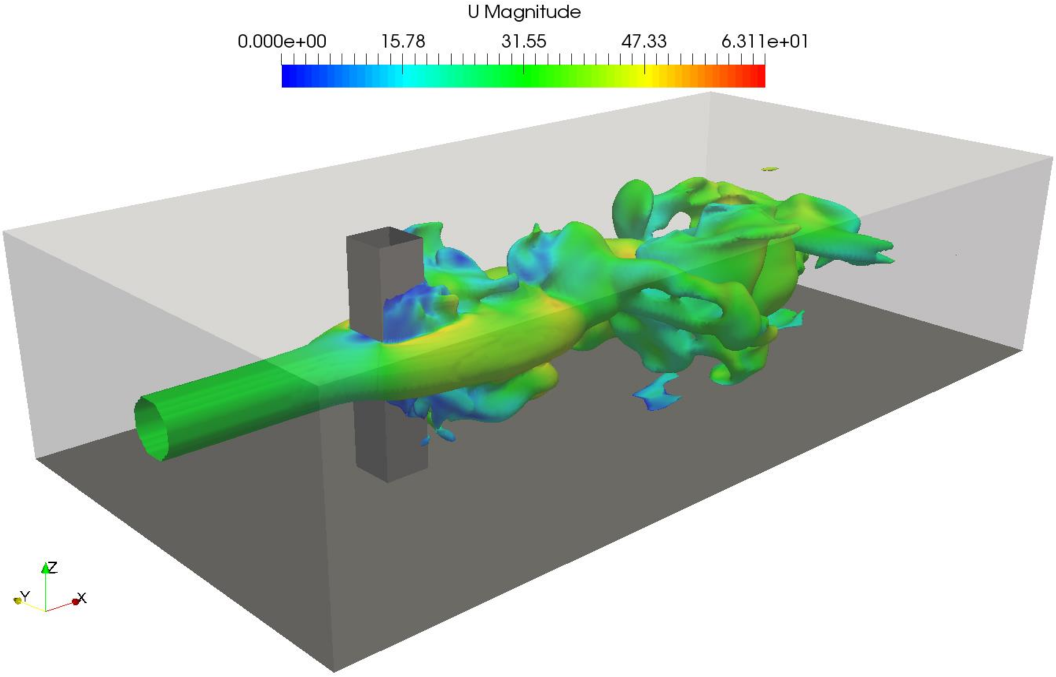


Fig. 5: Isosurface of instantaneous mass fraction Y = 0.05 colored by velocity magnitude.

4. Conclusions

There were done a few calculations of mass transfer past a square cylinder for moderate Reynolds numbers (Re = 6 600 - 20 000). The lower Reynolds numbers were investigated experimentally.

The study provides results of influence of Re on the concentration profile past the square cylinder. There was a significant effect of the blockage in the channel to the mass transfer in the crosswise direction of flow and also in the spanwise direction. The accumulation of mass behind the leading edge of the square cylinder led to the intense mass transfer in the spanwise direction.

Acknowledgement

This publication was written at the Technical University of Liberec as part of the project "Experimental and numerical investigation in applied fluid mechanics and energy devices" with the support of the Specific University Research Grant No. 21124, as provided by the Ministry of Education, Youth and Sports of the Czech Republic in the year 2017.

Computational resources were provided by the CESNET LM2015042 and the CERIT Scientific Cloud LM2015085, provided under the programme "Projects of Large Research, Development, and Innovations Infrastructures"

References

Abbassi, H., Nasrallah, S.B. and Turki, S. (2003) Two-dimensional laminar fluid flow and heat transfer in a channel with a built-in heated square cylinder. Int. J. of Thermal Sciences, 42, pp. 1105-1113.

Bošković-Vragolović, N., Garić-Grulović, R., Grbavčić, Ž. and Pjanović, R. (2013) Mass transfer and fluid flow visualization for single cylinder by the adsorption method. Int. J. Heat Mass Transfer, 59, pp. 155-160.

Bouris, D. and Bergeles, G. (1999) 2D LES of vortex shedding from a square cylinder. J. of Wind Engineering and Industrial Aerodynamics, 80, pp. 31-46.

Davidson, L., Norberg, C. and Sohankar, A. (1998) Low-Reynolds Flow around a Square Cylinder at Incidence: Study of Blockage, Onset of Vortex Shedding and Open Boundary Condition. Int. J. of Numerical Methods in Fluids, 26, pp. 39-56.

Lyn, D.A. (1995) A laser-Doppler velocimetry study of ensemble-averaged characteristics of the turbulent near wake of a square cylinder. J. of Fluid Mechanics, 304, pp. 285-319.

Rigas, F. and Sklavounos, S. (2004) Validation of turbulence models in heavy gas dispersion over obstacles. J. Hazard. Mater, A108, pp. 9-20.