

## LARGE EDDY SIMULATION OF FLOW THROUGH ARTIFICIAL MACRO-POROUS STRUCTURE

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**Abstract:** *Numerical study of flow through artificial macro-porous structure is presented. The Large Eddy Simulation (LES) approach with dynamic sub-grid scale model were performed using opensource software-OpenFOAM. The porous structure is created using an array of blocks. The effect of porosity of the artificial structure on turbulence properties is investigated.*

**Keywords:** **computational fluid dynamics, turbulent flow, large eddy simulation, openFOAM, porous structure**

### 1. Introduction

The motivation of the study is to further understand of the flow through a macro-porous structure in order to simulate in detail the adsorption process on activated carbon (Kořínek, 2017). The aim of this study is to point out an influence of porous structure on turbulence properties. Due to difficulties in creating sufficiently fine and well structured computational grid of real porous structure, a creation of an artificial porous structure is commonly used method for reducing the computational cost and for further understand the flow behavior (Jungreuthmayer et al., 2015). In porous structures and microchannels with holes as small as a mean free path of molecule, the continuum hypothesis is not valid and molecular dynamics simulation methods like the Direct Simulation Monte Carlo are used rather than the Finite Volume Method applied on the Navier Stokes equations (Tisovský, 2017). A crucial parameter is the Knudsen number which compares the molecular mean free path with a characteristic length scale.

$$K_n = \frac{\lambda}{L}, \quad (1)$$

where  $\lambda$  is the mean free path of molecules and  $L$  is characteristic length scale. It has to be mentioned that this study was a complex problem, where macro-porous and micro-porous structure were incorporated into one domain. The Knudsen number for the macro-porous region was  $K_n = 1.8 \cdot 10^{-8}$  and  $K_n = 0.029$  for micro-porous region.

### 2. Porous structure

The porous structure was represented by array of simple blocks each representing micro-porous element. In order to simplify the problem, only flow through the macro-porous structure was modelled and the micro-porous structure was represented by a source of pressure drop. Approach used is significantly different from the approach traditionally used for modelling flow through porous structures (Zhang et al., 2017; Jungreuthmayer et al., 2015). In this case, number of structures with different dimensions of blocks and width of the slot between blocks were created. An overview of tested cases is shown in Tab. 1.

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Tab. 1: Case study

case	size of the micro-porous block (mm x mm)	width of the slot (mm)
B1	5 x 5	5
B2	5 x 3.7	2.5
B3	2.5 x 2.5	2.5
B4	2.5 x 2.5	1.25

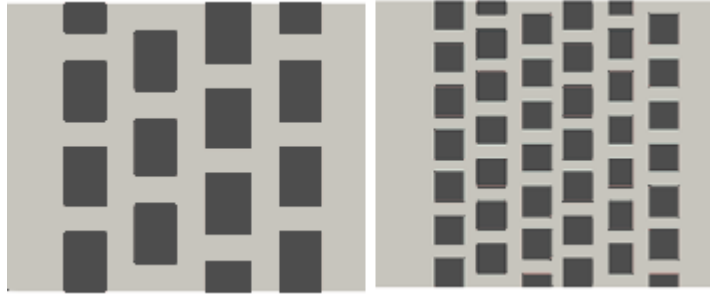


Fig. 1: Artificial porous structures B2 (left) and B4 (right)

The dimension of the channel containing macro-porous structure were as follows: height= 10 mm, width= 25 mm and length= 100 mm. The artificial structure created is shown in Fig. 1, where a light gray color corresponds to the fluid and a dark gray color is related to the micro-porous structure.

### 3. Numerical strategy

The fully 3D numerical simulation using the Large Eddy Simulation (LES) approach was performed to obtain velocity and pressure field. The filtered unsteady governing equations for incompressible fluid flow are:

$$\frac{\partial \bar{u}_i}{\partial t} + \frac{\partial \bar{u}_i \bar{u}_j}{\partial x_j} = -\frac{1}{\rho} \frac{\partial \bar{p}}{\partial x_i} + \frac{\partial}{\partial x_j} \left[ (\nu + \nu_{sgs}) \frac{\partial \bar{u}_i}{\partial x_j} \right] + R_i, \quad (2)$$

where  $p$  is pressure,  $R$  is pressure loss of micro-porous block based on Darcy-Forchheimer law,  $u$  is velocity,  $\nu$  is kinematic viscosity,  $\nu_{sgs}$  is sub-grid scale eddy viscosity,  $\rho$  is density. And transport equation for sub-grid scale kinetic energy is:

$$\frac{\partial k_{sgs}}{\partial t} + \frac{\partial \bar{u}_i k_{sgs}}{\partial x_i} = 2\nu_{sgs} \bar{S}_{ij} + C_\epsilon \frac{k_{sgs}^{3/2}}{\Delta} + \frac{\partial}{\partial x_j} \left( \nu_{sgs} \frac{\partial k_{sgs}}{\partial x_j} \right), \quad (3)$$

where model constant  $C_\epsilon = 1.048$ ,  $k_{sgs}$  is subgrid scale kinetic energy,  $S_{ij}$  is strain rate tensor,  $\Delta$  is the cubic root of the volume of computational cell. The first term on right side represents the production of sub-grid scale kinetic energy, the second term is dissipation and the third term is diffusion. The sub-grid scale eddy viscosity  $\nu_t$  is defined as:

$$\nu_{sgs} = C_k \Delta \sqrt{k_{sgs}}, \quad (4)$$

where model constant  $C_k = 0.094$ . Due the problem with incorrect behaviour of  $\nu_{sgs}$  near wall, the van Driest damping function was used.

A divergence free synthetic eddy method introduced by (Jarrin et al., 2009) and improved by (Poletto et al., 2013) was used to initialise turbulence on inlet. The bulk velocity at inlet was 5 m/s. The Crank Nicolson

scheme was chosen for temporal discretization for its second order accuracy. The PISO algorithm was used to solve the governing equations. Tolerance of residuals was set to  $10^{-7}$  for pressure and  $10^{-6}$  for velocity and subgrid scale kinetic energy. Time step size was chosen based on the Courant Friedrich Lewy condition (CFL) with value of  $CFL=0.1$  for an initialization of the simulation and for the averaging part, the time step size was chosen based on the mean time step size from the initialization.

Four computational meshes were generated in order to perform mesh independence study with various number of cells for each mesh (673 920, 1 073 250, 1 500 000, 2 171 650). However the coarsest mesh still satisfied the condition  $y^+$  at the wall should be around 1. The mesh study was performed on the case B1 and results from the mesh study were used for creation of computational grids for cases B2 (2 964 000), B3 (8 370 000) and B4 (16 773 480).

#### 4. Results

An influence of porous structure on vortices is shown in Fig. 2 using an iso-surface of Q-criterion. The iso-surfaces are both for the same value of normalized Q-criterion. The upper image is for the structure B1 and the lower image is for the structure B3. Smaller vortex structures are generated for the structure B3, which is more detailed in comparison with structure B1. It has been noted by (Bošković-Vragolivić et al., 2013) that with increase of bulk velocity, mass transfer to the structure is also increasing. Also the more detailed structure has a twice bigger surface of blocks, which leads to greater mass transfer to these blocks. However greater blockage results in increase in pressure loss.

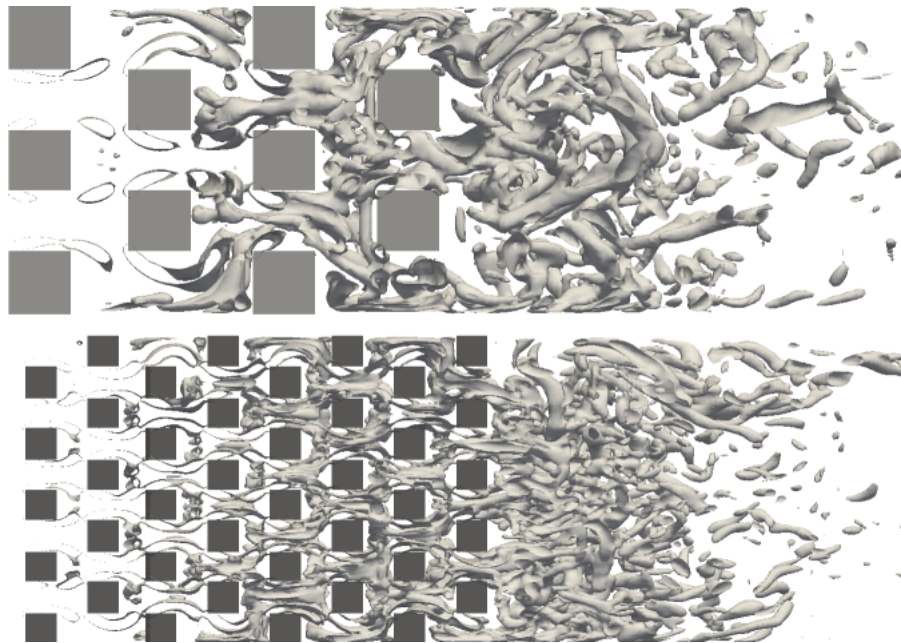


Fig. 2: Instantaneous iso-surface of Q-criterion for artificial structure B1 (up) and B3 (down).

It has to be pointed out that not only mean velocity has an influence on mass transfer, there is also influence of fluctuating part of velocity on intensity of mass transfer to the structure. Tab. 1 shows turbulence intensity for various artificial structures. A very interesting phenomenon is occurring for situation of different dimensions of block and slot. If the dimensions differ, the turbulence intensity is greater than for case where dimensions are same.

Tab. 2: An influence of structure on turbulence intensity

Structure	B1	B2	B3	B4
Turbulence intensity (%)	10.2	28.1	9.48	26.4

## 5. Conclusions

The macro-porous artificial structure with micro-porous elements were numerically investigated by LES. Various structures were compared to each other in order to evaluate critical parameters which have influence on mass transfer to the micro-porous elements.

Turbulence intensity was more influence by the ratio of the block width and the width of the slot, than the size of the block itself. If the size of the block and the size of the slot were same, turbulence intensity was lower than for case where dimensions differ. Simulations were performed for isothermal flow. Simulations of a non-isothermal flow will be carried out in the future.

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