Experimental and numerical study of velocity profiles in FGD reactor

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Abstract: This article describes the investigation of velocity fields inside the flue gas desulfurization reactor. This reactor is self-constructed for using as experimental verification tool in research of modeling the desulfurization process. During the experimental study the velocity field at the inlet of the reactor and inside the spray zone were measured. Obtained values of velocity at the inlet were used to set boundary conditions for CFD. For CFD modelling of the flow inside the reactor software OpenFOAM with its utilities was used. CAD model of the reactor was edited to the simplified geometry of fluid inside and several different computational meshes with different element size were created. After that CFD simulations were performed to study the effect of mesh size to results of simulations (velocity fields). At the end results obtained from experiments and from CFD were compared. Based on the comparison the requirements for the computational mesh and CFD solver parameters to gain good agreement with the real state were specified.

Key-Words: desulfurization, reactor, flow, velocity profile, CFD, OpenFOAM

1 Introduction

In the Czech Republic the most electricity is produced by coal power plants. Amount of pollutants, which are harmful for the environment (e.g. NO_x, SO_2…), has to be reduced under the legal limits. For reducing sulfur dioxide the devices called wet scrubbers are used.

These scrubbers looks like several tens of meters tall and few meters wide cylinders. Process inside the scrubber is called flue gas desulfurization (FGD). Principle of wet FGD is based on absorption of sulfur dioxide into a droplets of limestone slurry. Inside the scrubber there is multicomponent multiphase flow. It could be simplified to flow of ideal gas with limestone slurry droplets [1].

The whole chemical process is very complicated, description of particle steps needs tens of chemical equations. There is an effort to simplify the description to several equations for using in CFD modelling.

Main chemical reactions are described with following equations [2]:

$$\mathrm{SO_2 + CaCO_3(s) \rightarrow CaSO_3 + CO_2} \quad (1)$$

$$\mathrm{CaSO_3 + 0.5O_2 \rightarrow CaSO_4(s)} \quad (2)$$

In fact the main products of these reactions are CO2, which is exhausted to atmosphere, and gypsum CaSO4, which could be used for making materials for civil engineering.

Bravo et al. in [3] described the division of the main reactions (1), (2) and physical steps of absorption into several steps. These steps include diffusion, dissolution and dissociation of SO2 and dissolution of CaCO3. Reaction kinetics of these processes may be affected by various influences, e.g. operating temperature, concentration of reactants, partial pressure etc.

Complex mathematical model of FGD process including multiphase flow with limestone slurry droplets and chemical interaction between phases was clearly and concisely described by Goméz et al. in [4] and Marocco et al. in [5],[6]. They described the approaches to CFD simulations of desulfurization process applicable to real power plant equipment.

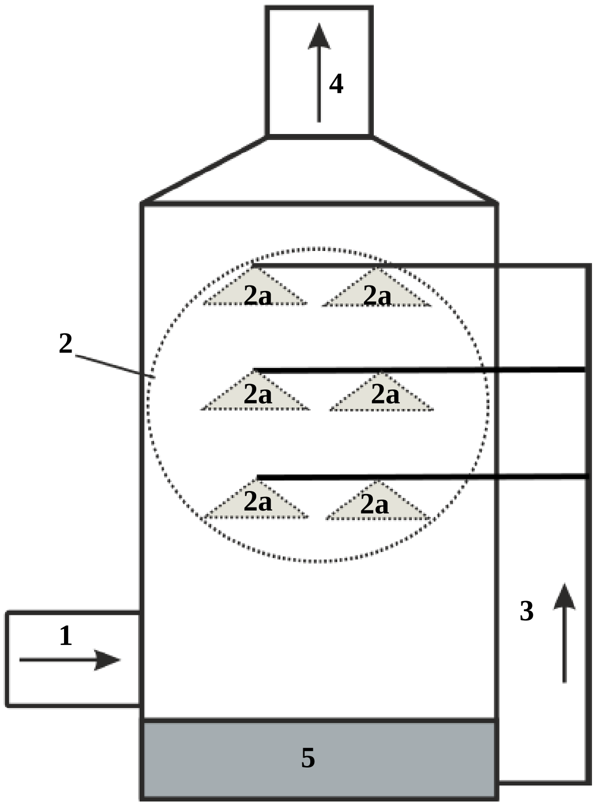
The aim of our work is to develop the numerical model of FGD process implemented into OpenFOAM computation software.

In work [7] we found that we need to build a scaled model of FGD reactor to verify the numerical results.

Aim of this work is to show velocity fields measured inside the experimental reactor in comparison with velocity fields gained from numerical simulation.

2 Experimental FGD reactor

Based on the cooperation with specialists from company *DIZ Bohemia* Ltd., the experimental FGD reactor was built. It represents a scaled model with typical proportions of FGD reactors, which are implemented in Czech coal power plants. The reactor also includes parts, which are designed to be modified based on our needs for future research.

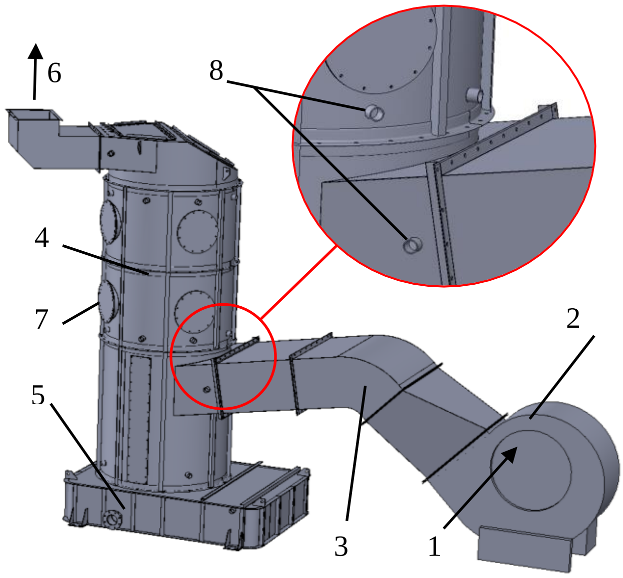


1 – inlet of flue gas
2 – spray zone
2a – spraying nozzles
3 – circulation of slurry
4 – outlet (cleaned gas)
5 – slurry tank

Fig. 1 Schematic sketch of FGD

A schematic sketch of the FGD reactor is shown in figure 1. In spray zone (2) limestone slurry is sprayed by spraying nozzles (2a) into the flow of flue gas. Sulfur dioxide is absorbed by limestone slurry droplets. The cleaned gas flows to the outlet and gypsum particles as a product of chemical reactions of limestone and SO2 fall down by gravity to the tank (5) in the bottom part of reactor.

The whole design of scaled model built by DIZ Bohemia is shown in figure 2 and figure 3. In principle it coincides with the scheme shown in figure 1. The main cylindrical part of the reactor is 5 m height and it´s diameter is 1.6 m. This reactor is currently designed for use air from surroundings instead of flue gas. Air is blown into the reactor by radial fan. Amount of air flown to the reactor could be controlled by changing rounds of the fan. This is allowed by frequency converter connected to the fan engine. For the experimental study of velocity fields inside the reactor, the spraying nozzles and devices for circulation of slurry have not been installed. Outlet of the reactor is opened to the surroundings.



1 – suction of air
2 – radial fan
3 – inlet pipe
4 – spray zone
5 – tank
6 – outlet of air
7 – transparent flange
8 – nipples

Fig. 2 Assembly of reactor and fan – CAD model

Fig. 3 Assembly of reactor and fan – photo

2.1 Experimental setup

Flow of gas inside the FGD reactor is very important for studying the desulfurization process. Because of quite huge dimensions of the scaled reactor (several meters in order) it is not possible to find the full velocity field inside.

2.1.1 Area of interest

The most important area for us is the spray zone. Through this area under the area for spray nozzles there were installed several nipples in three different levels Z1, Z2, Z3 (see figure 4).

In each level 33 measuring points across the section were defined. Scheme of point´s position same for all levels is shown in figure 5. Labeling of points is based on numbers of point´s row and number of point in row (increasing in radial direction from the center).

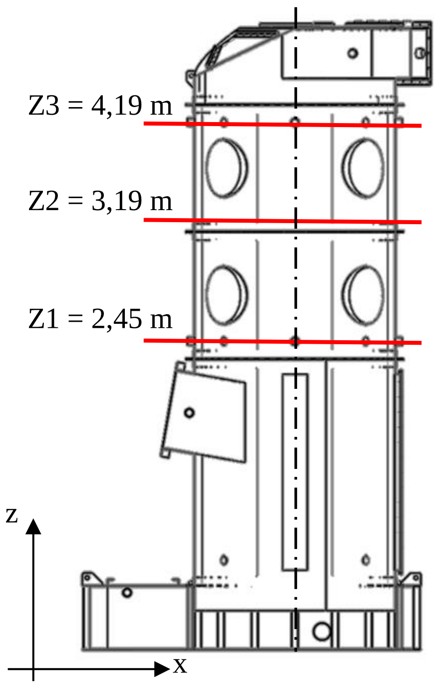


Fig. 4 – Reactor – Position of section planes

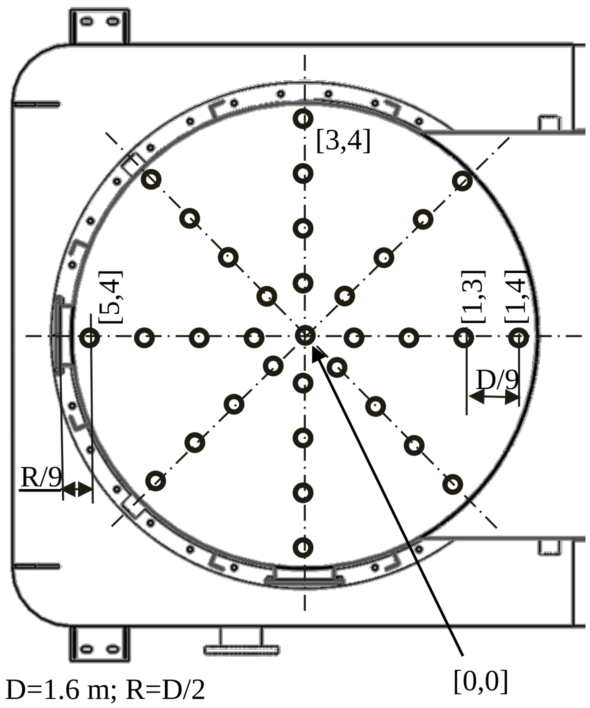


Fig. 5 – Measuring points – scheme and labeling

2.1.2 Measuring devices and setup

For measuring velocity the system with Prandtl probe was used. The whole device consists of the Prandtl probe with 1m length, connecting silicone hoses and Testo 480 climate measurement meter and data logger. This device connected to the Prandtl probe measure differential pressure and convert that directly to the value of velocity shown on the display. Values are also stored to the inner memory of the device from which could be exported to PC for evaluation.

The function scheme of the apparatus described in the previous paragraph is shown in figure 6 . Prandtl probe is inserted through the concrete nipple and is traversed by hand only in horizontal direction to measure velocity in different points (see figure 5). It should be mentioned that the end of Prandtl probe was oriented in –Z direction, so only the z-component of velocity was measured.

Flow rate has been set to match the operating mode, which is represented by 40% of power on frequency converter.

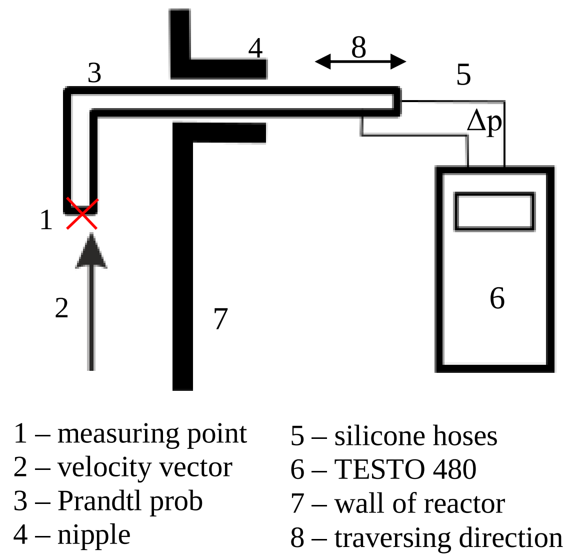


Fig. 6 – Block scheme of experimental setup

2.2 CFD

For CFD simulation of flow inside the FGD reactor the OpenFOAM software have been used. The goal of simulation is to numerically simulate the whole desulfurization process. Our investigation aimed to development of the suitable solver. It is a modification of standard coalChemistryFoam solver included in OpenFOAM.

2.2.1 Geometry and mesh

Geometry is based on the CAD model of experimental reactor. Before making computational mesh the whole geometry was simplified, some features like chamfers, small holes etc. were deleted and the volume extraction was performed to gain the volume of fluid inside the reactor (see figure **7**). For these modifications ANSYS Space Claim Direct Modeler was used.

After that the computational meshes were created using Ansys Meshing utilitiy. For next study of influence of element size on results, four hexahedral meshes with different element size (quality) were created. All variants of meshes with element size are shown in figure **8**. Boundary layer has not been modeled because of neglected dimensions of that in comparison with whole reactor dimensions. Meshes were exported from ANSYS Meshing to *.msh format and then imported to OpenFOAM environment by function „fluent3DMeshToFoam“.

2.2.2 Boundary conditions

Boundary conditions were set in agreement with the experiment. Inlet velocity was obtained from measurement, it is 5 m/s. Other boundary conditions are shown in figure **7**.

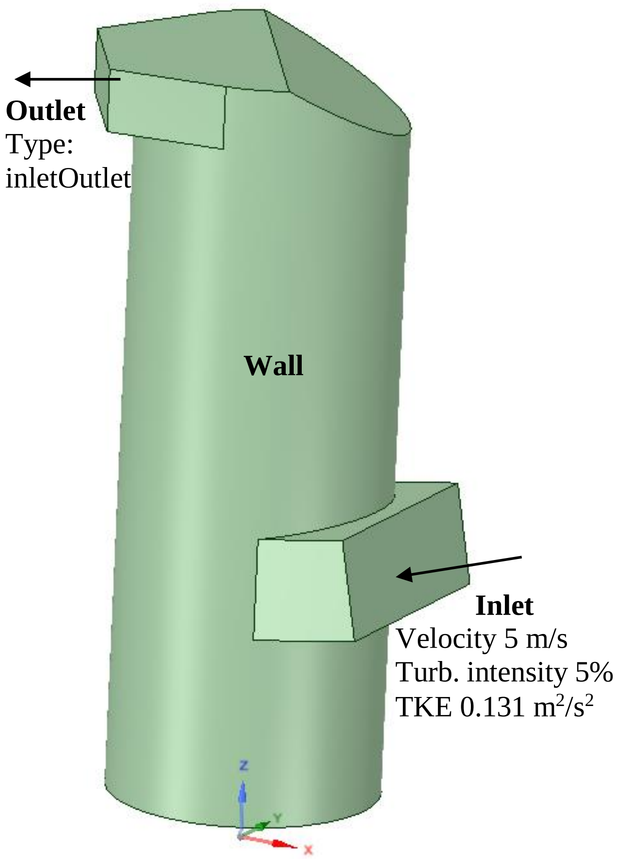


Fig. 7 – Fluid volume with boundaries

2.2.3 Calculation setup

Calculation is conceived as transient flow of air through the reactor. Air is considered as ideal gas with constant properties. K-ω SST model was used. Residuals of momentum and turbulent quantities were set to 10^{-3}, residuals of energy to 10^{-6}.

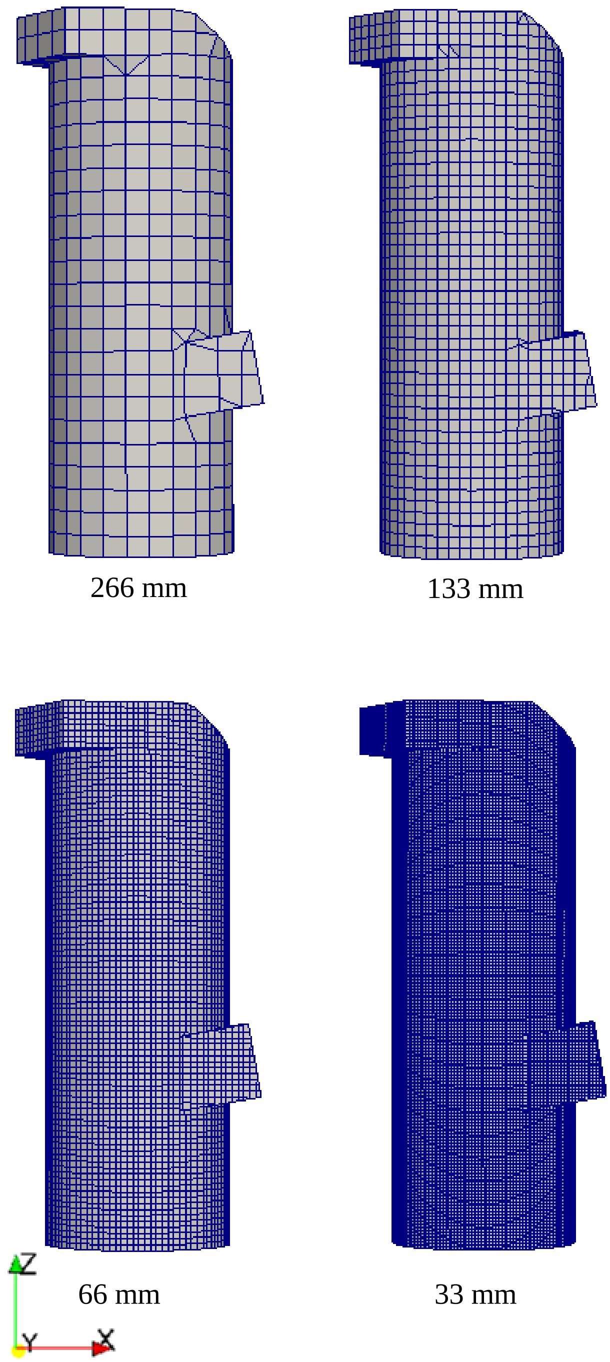


Fig. 8 – Computational meshes labeled by different element size

3 Results assessment

For both methods (experiments and CFD) the velocity fields in previously described areas were obtained.

3.1 Experimental data

From measurement with Prandtl probe the velocity fields in three levels of the scrubber totally in 99 measuring points were obtained. Data saved in data logger TESTO were analyzed. As was written in chapter 2.1.2, the velocity values in z- direction were measured. Results of measuring velocity are shown in figure 9.

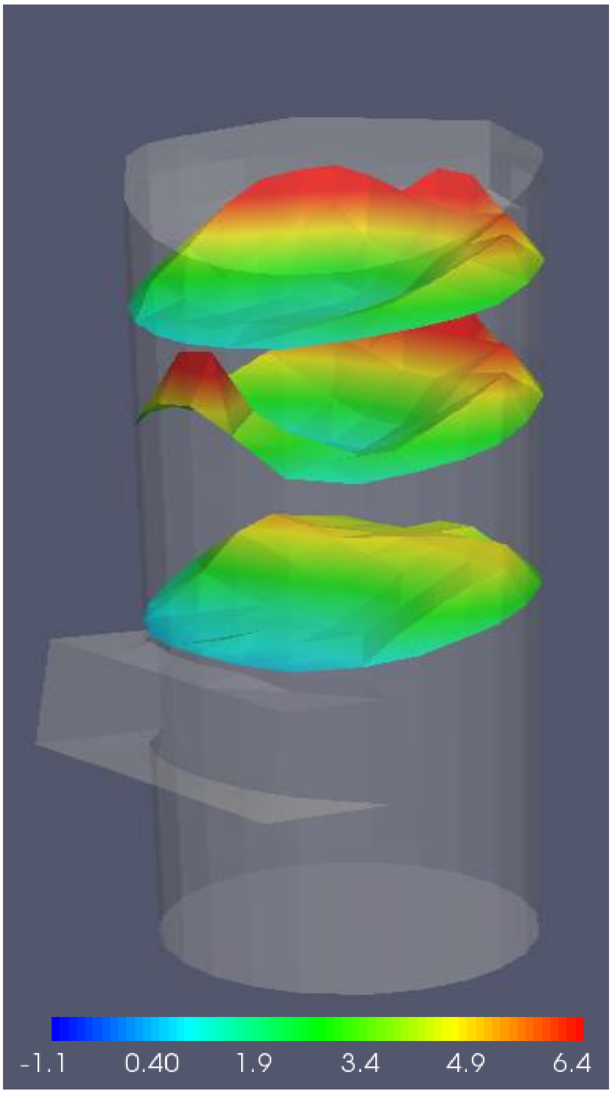


Fig. 9 – Velocity field (exp.) – z-velocity (m/s)

3.2 CFD analysis

From CFD analysis were obtained velocity fields for different mesh types. Because only the z-direction velocities was obtained from the experiment, the results from CFD are shown in the same way, only velocities in z-direction (see figure 10). For better illustration of differences between experiment and CFD, results from experiment and CFD for the finest mesh are shown side by side in figure 11.

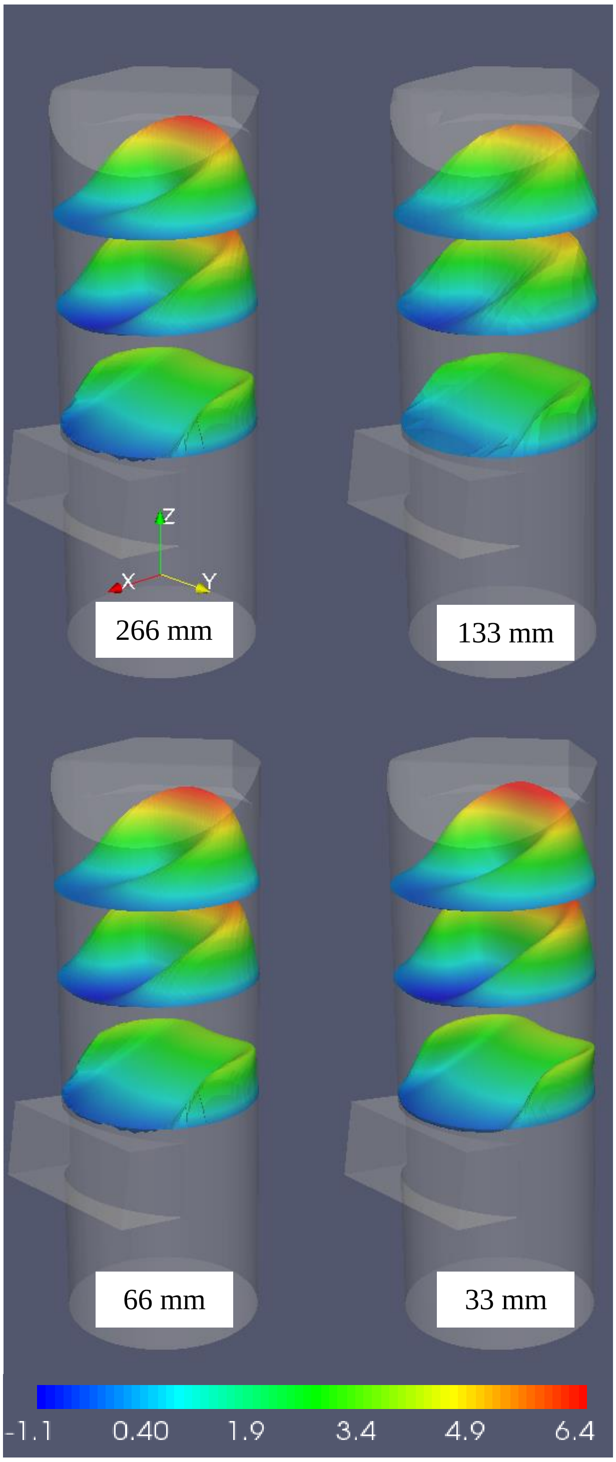


Fig. 10 – Velocity fields (CFD) – z-velocity (m/s) for meshes with different element size

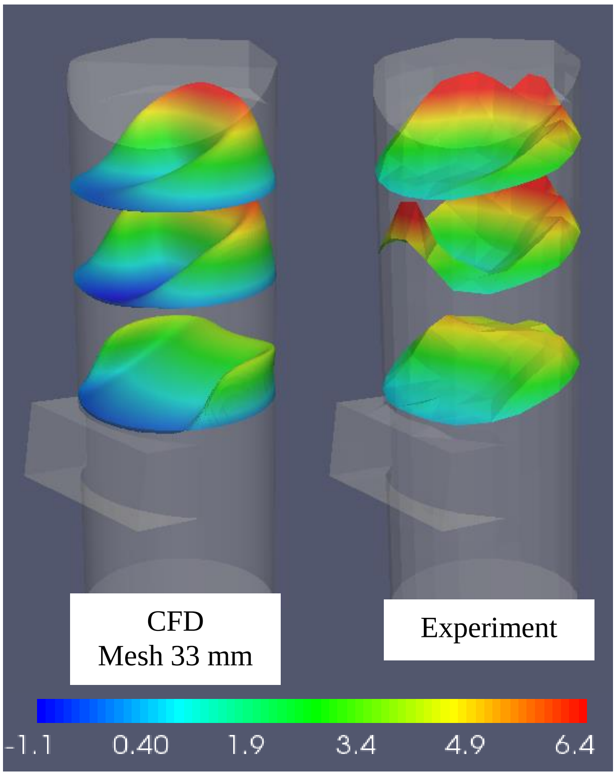


Fig. 11 – Velocity (comparison) – z-velocity (m/s)

4 Conclusion

In this work the investigation of velocity fields inside the FGD reactor by experimental and numerical methods was performed. The geometry of real device was transformed to the numerical model and the input parameters to the model was set to correspond well with experimental setup.

Experimental part was performed with using the possibilities of experimental reactor (e.g. nipples as entrances for inserting Prandtl probe inside the spray zone) and available equipment. As we can see from the results published in figure 9, in the velocity profile in the middle level is several points with quite high velocity than in neighbors point. It is probably the measurement error. It could be caused by worse positioning of the probe, or because we have measured only the z- component of velocity and in these area the velocity vector may not be in accordance with this direction. For the future the possibility of using device for traversing the probe should be considered.

In numerical methods several types of computational meshes were used. From the obtained results we can say, that the element size did not affect the velocity fields in the spray zone a lot. For all images shown in figure 10 could be said that the flow is dominant on the right side, which is the side far from the inlet. That is because the flow which enters the reactor is forced to change the direction from x-direction to dominantly z-direction flow. The blue areas shown probably the backflow area. For the future these areas could be affected by adding the nozzles into the spray zone and if not, it will be good to think about changes of the geometry of inlet pipe to gain better distribution of air in the spray zone.

From figure 11 it could be said that very good accordance of results was reached. Some differences are in the area with lower velocities, it could be caused by measuring device accuracy and by flow fluctuations, because the measured values were time averaged.

Acknowledgement

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