NUMERICAL MODELLING OF BLAST FURNACE GAS FLOW IN WATER SEPARATOR

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Abstract

Blast furnace gas, which is created as a by-product during the ironmaking, belongs to the less valuable fuels due to its low heating value. Due to BF gas parameters (high amount of gas and high content of CO), it is used as an energy source for the preparation of preheated air in the stoves or for the heating of industrial furnaces. In addition to low heating value, BF gas contains a large amount of dust. In order to prohibit reduction of the heating value of the gas, the gas must be cleaned by a gas cleaning system. Gas cleaning includes two phases: dry cleaning including dust catcher or cyclone and wet cleaning including scrubber, Venturi tubes and water separator (demister, droplet separator). The water separator is a cylindrical vessel with a diameter of 4 to 6 m and a total height of 25 m. During the gas flow in the separator, the water droplets and dust particles are trapped and deposited on the walls, and subsequently carried away in the form of sludge at the bottom of the separator. The main problem with gas cleaning in the separator is the location (shape, dimensions) of the inlet and outlet of gas to and from the separator. In order to achieve the maximum gas cleaning efficiency, a primary simulation of the gas flow through the separator was performed by numerical modelling in the CFD program ANSYS Fluent. In the following stages, optimization of the internal arrangement of the separator will be carried out.

Keywords: Blast furnace, blast furnace gas, gas cleaning, water separator, numerical modelling

1. INTRODUCTION

Blast furnace (BF) gas belongs to the less valuable fuels due to its low heating value (2800 - 3600 kJ.m^{-3}). However, blast furnace generates big volumes of BF gas, so it plays an important role in the energy balance of metallurgical plants [1]. BF gas contains a relatively high amount of carbon monoxide - CO (up to 25 vol.%), and for these reasons, it is repeatedly used as an energy source for various heating processes, for example, for preparation of heated air in hot stoves or for the heating of the industrial furnaces [1-6]. It is an economically and environmentally acceptable and commonly used solution. In addition to low heating value, the BF gas contains a large amount of dust (approx. 30-40 g/(N·m^3)). In order to prohibit reduction of the heating value of the gas and to ensure its overall quality for further use, the blast furnace gas has to be cleaned. Blast furnace gas cleaning includes two phases: dry (coarse) gas cleaning in dust catcher and wet (semi-fine and fine) gas cleaning. After complete gas cleaning, BF gas leaves the cleaning system with dust content of up to 10 mg/(N·m^3). The main equipment of BF gas wet cleaning system includes scrubber, Venturi tubes and water separator [1-6]. The water separator is a cylindrical vessel with a diameter of 4 to 6 m and a total height of 25 m. During the gas flow in the separator, the water droplets and residual dust particles are trapped and deposited on the walls, and subsequently carried away in the form of sludge at the bottom of the separator [1-6].

For reusing the BF gas as a medium for preparation of heated air in the hot stoves, it is desirable that the gas entering the gas preheating equipment contains the moisture as low as possible. The gas preheating equipment (using a heat transfer surfaces) transfers the heat to the treated BF gas, which is flowing to the hot stoves. If the BF gas moisture is too high, the residual solids content in the individual sections of the gas preheating equipment is accumulated, and due to the residual moisture content, the solid crust in these sections is formed. In these cases, the gas preheating equipment loses the ability to use the residual heat effectively. The basis of any gas cleaning plant operation is, therefore, the effective removal of excess moisture during the BF gas wet cleaning in the water separator by providing its optimum parameters (geometry, gas inlet and outlet, gas flow, gas velocity, etc.) [7-10]. In order to achieve the maximum water droplets separation, a primary simulation of the gas flow through the water separator was performed by numerical modelling in the CFD program ANSYS Fluent. In the following stages, optimization of the internal arrangement of the separator will be carried out.

2. MODELLING APPROACH

In this work, the primary numerical simulation of blast furnace gas flow through the water separator was performed in CFD software ANSYS Fluent 17.0. The fluid flow has been mathematically described by a set of partial differential equations implemented in software, such as especially Navier-Stokes equations. The solution of Navier-Stokes equation is based on the Reynolds average Navier-Stokes (so-called RANS) equations [11]. Due to the expected tangential flow phenomena of blast furnace gas flow inside the separator, the standard turbulence k-epsilon model was used primary. Because of the fluctuation of turbulent fluid flow, the Reynolds Stress Model (RMS) was also verified, but without another efficiency. The modelling of particles flow was neglected. The SIMPLE algorithm of the solution under Steady-State conditions was used. The defaults Under-Relaxation Factors were set. The Relaxation Factor $\alpha < 1$ is used for stabilization of calculation. If $\alpha = 1$, no relaxation is considered and the variable value is applied. The $\alpha > 1$ can accelerate the calculation, but the calculation stability is worse. To get a much more accurate solution, the residuals were set to 10^{-6} [12].

2.1. Geometry of the system

The geometry of the water separator for numerical modelling was created in ANSYS DesignModeler (ADM) preprocessor. The basic geometry looks very simply (see **Figure 1a** [13]). The water separator consists of three main parts: inlet section, internal volume with the pyramid bottom for trapping sludge and from the gas outlet pipe. As it was mentioned above, the main aim of the water separator is to remove the dust particles from the blast furnace gas and at the same time to decrease the content of residual moisture during the gas flowing through the separator. Therefore, the optimal position of the inlet and outlet area, and also the internal arrangement, has to be designed. In the past, the inlet area of this separator was placed at the top part of the main volume (see **Figure 1b** [13]). Last year, the position of the inlet area was changed depending on the experience. Now, the inlet is in the lower part of the separator and it is located tangentially. To achieve the idea concerning the flow character in new design separator, the research with the use of numerical modelling has to be started.

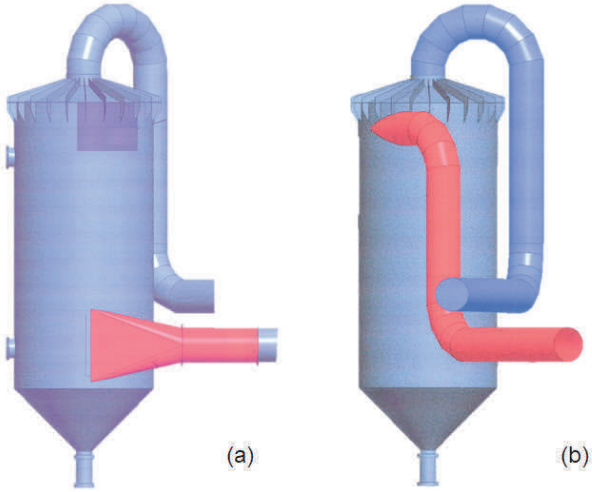

Figure 1 The geometry of water separator (a) new design (b) older version [13]

2.2. Computational mesh

The geometry of the separator prepared for modelling in ADM was simple (see **Figure 2a**), but during the mesh generation, the problem with the thin plate of the outlet pipe and also at the leading edge of the inlet area was detected (see **Figure 2a, 2b**). There was a very small thickness of the pipe wall in comparison with the rest of the main volume. Also, between the wall of the separator and the wall of the inlet, there was a very acute angle. The orthogonal quality (OQ) was close to the value of 1 and skewness (S) was especially about the value of 0 for the almost main volume of geometry (which means very good quality of the mesh), but on the edge of the pipe plate with thickness 10 mm the OQ was lower than 0.20. The deformation of mesh elements can lead to divergence of calculation. Therefore, it was necessary to modify the meshing method by the use of the Edge Sizing to specify the mode of division of the selected face very precisely. The final mesh consisted of approx. 3 mil. tetrahedral elements (see **Figure 2c, 2d**), which made the calculation highly time-consuming. In the following steps of research, the attention will be devoted to the next optimization of the model mesh.

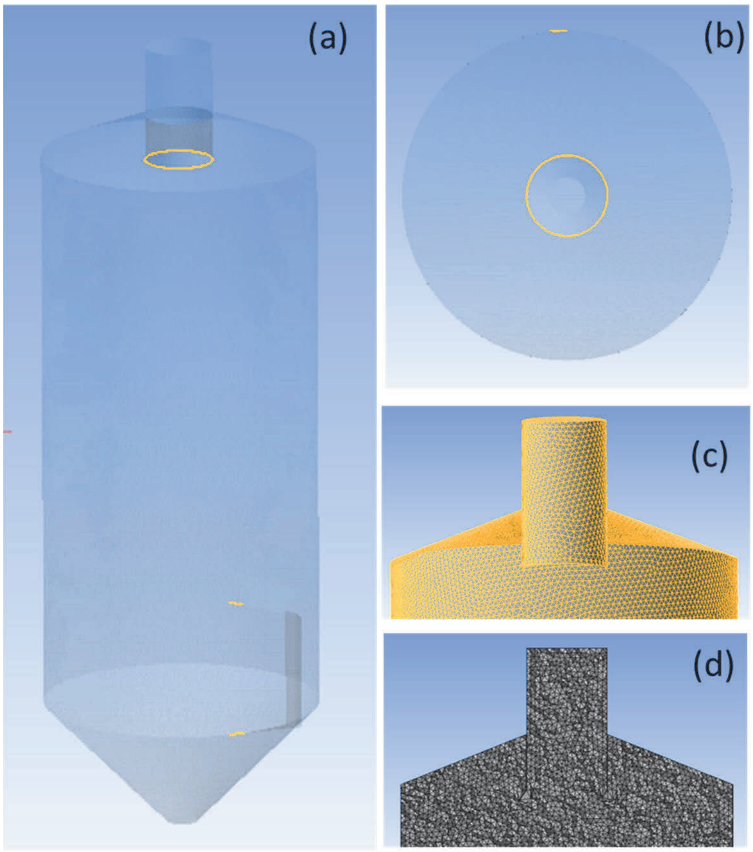

Figure 2 The steps during the computational mesh generation of water separator geometry **(a)** and **(b)** Problem detection with Orthogonal and Skewness Quality **(c)** Surface Mesh **(d)** Volume Mesh

2.3. Physical properties

Blast furnace gas is classified as a hazardous substance according to European Parliament Regulation No. 1272/2008 because it is flammable, explosive when heated and toxic when inhaled. Blast furnace gas is a mixture of gasses that contains carbon monoxide, hydrogen, carbon dioxide, nitrogen, and occasionally traces of methane in the case when natural gas is used for a bell-less top. The percentages of individual gasses in the blast furnace gas are given in **Table 1**. **Table 2** contains the physical properties necessary to define a numerical model, such as relative density at 20 °C and a dynamic viscosity. Physical properties were determined according to available literature data [14, 15].

Table 1 Chemical composition and a percentage of components in blast furnace gas (wt.%) [14]

CO	H_2	CO_2	N_2
18.3 - 23.9	0.2 - 0.4	23.0 - 26.1	46.0 - 56.0

Table 2 Physical properties of blast furnace gas used for numerical modeling [14, 15]

Physical parameter	Unit	Value
Relative density	$kg·m^{-3}$	1.250
Dynamic viscosity	$kg·m^{-1}·s^{-1}$	$1.8·10^{-5}$

2.4. Boundary and operating conditions

The inlet parameter of the blast furnace gas flow into the water separator was already defined as VELOCITY-INLET. The velocity came up to 30 $m·s^{-1}$. The boundary condition at the separator outlet was set up as a so-called OUTFLOW boundary. The gravity was -9.81 $m·s^{-1}$ and operation pressure 101,325 Pa. The wall was considered to be a stationary wall with no roughness.

3. DISCUSSION OF RESULTS

Figure 3 represents the velocity vectors in the cross-section along the height of the separator. **Figure 4** demonstrates the pathlines of the calculated tangential character of the velocity magnitude of the gas flow through the separator. **Figure 5** than shows the changes in the velocity vectors for the individual cross-section along the height of the separator.

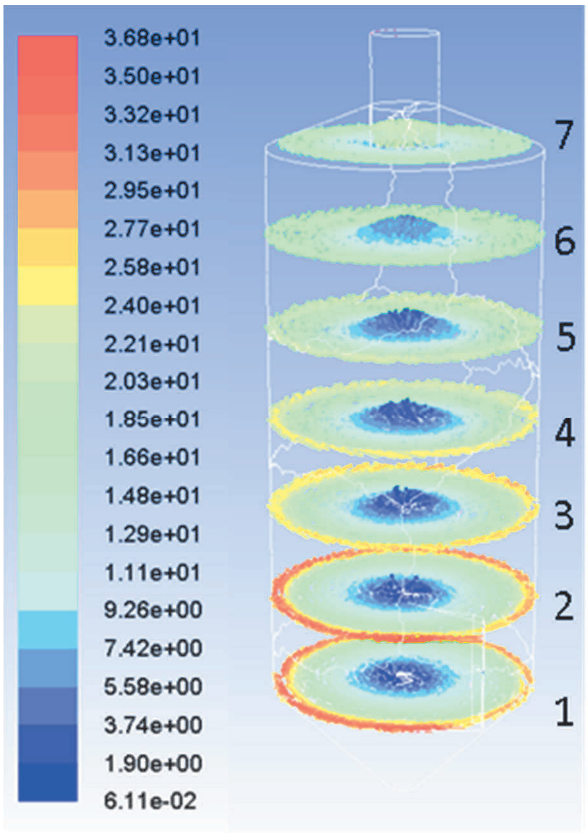

Figure 3 Velocity vectors in the cross-section along the height of the water separator ($m.s^{-1}$)

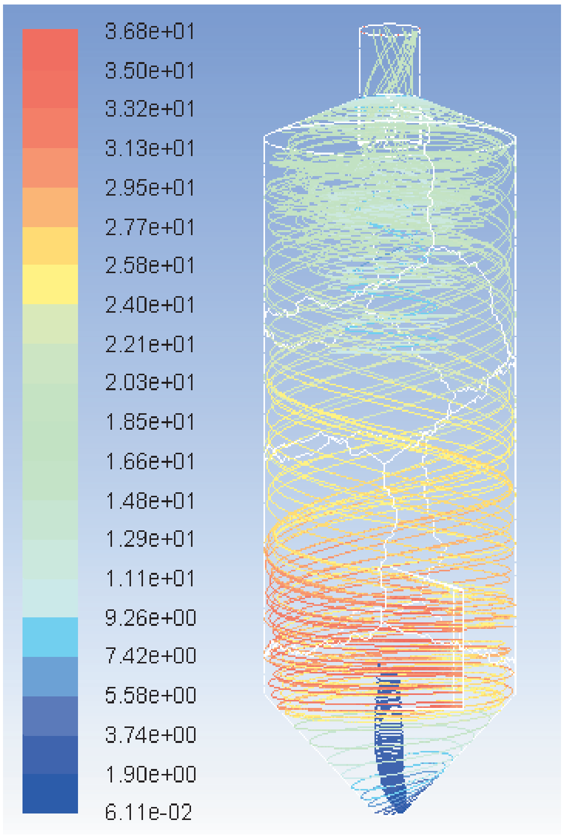

Figure 4 Pathlines of the calculated tangential character of velocity magnitude ($m.s^{-1}$)

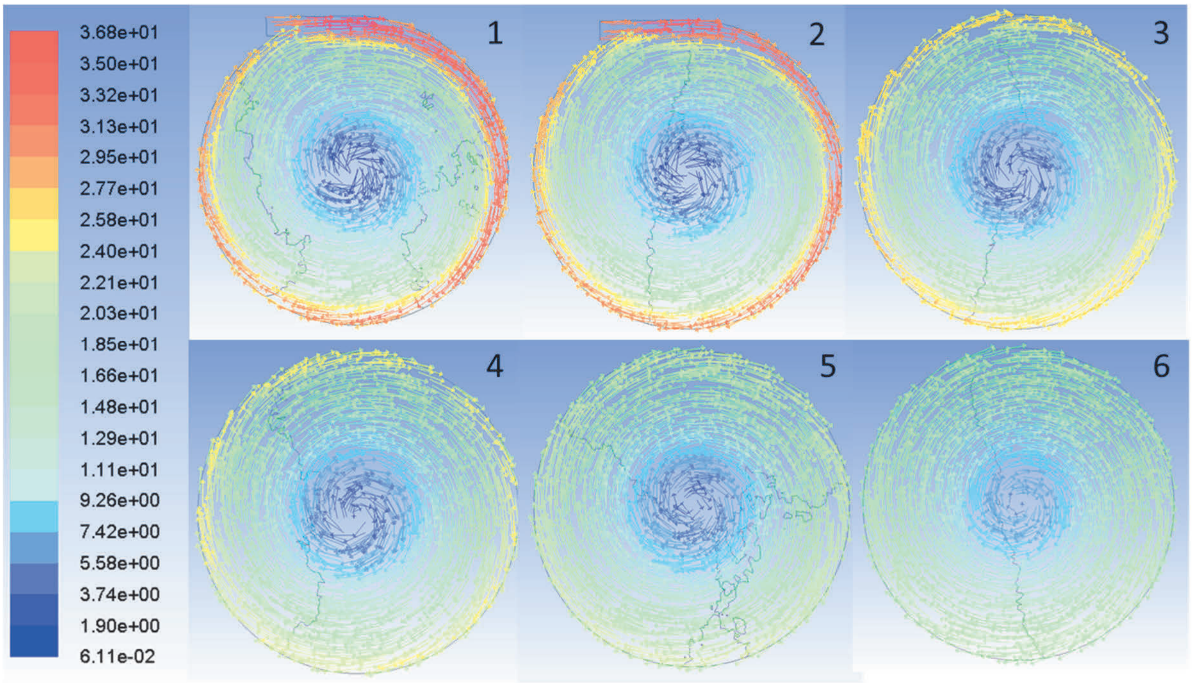

Figure 5 The changes in velocity vectors (m·s^{-1}) for the individual cross-section (as in Figure 3) along the height of the separator

Figures 3 - 5 show the typical fields of blast furnace gas flow through the water separator. The tangential position of the inlet area distributes the gas tangentially along the wall from the bottom of the separator to the upper part with the outlet. Due to the loss of kinematic energy, in the middle of the flow field it is possible to see the decreasing velocity. This character of flowing can positively influence the separation of water droplets and dust particles from the gas. The particles are for a longer time in contact with the separator wall and due to the friction they can adhere. If some particles are moved to the upper part, the low flow velocity in the middle of the separator together with a higher density of particles can lead to tearing them down. Also, the gas with particles has enough time to remove the residual moisture.

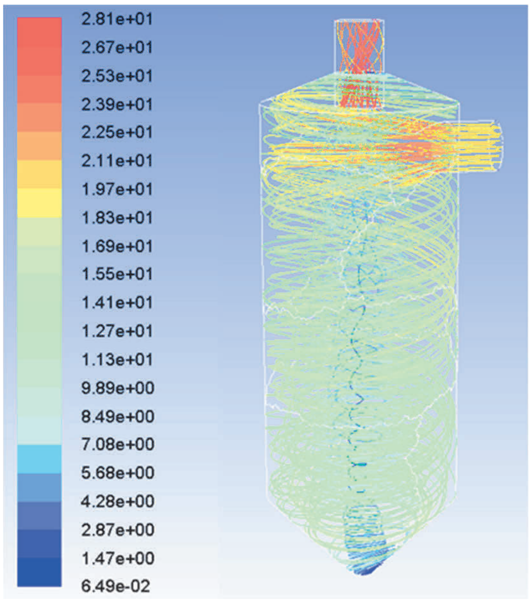

Figure 6 The character of blast furnace gas flow in water separator with originally orientated inlet

To achieve the idea concerning the influence of position of the inlet area on the final gas flow field in the separator, the originally orientated inlet was also numerically verified in the end. As it can be seen from **Figure 6**, in the original arrangement of the separator, a sufficient inlet speed was not achieved. As a result of the lower inlet velocity, there is a greater degree of gas movement disorderliness in the area below the inlet, which can reduce the efficiency of the separator.

4. CONCLUSIONS

The paper presented the primary numerical verification of the blast furnace gas flowing in the water separator. The main findings from the research are the following:

- Blast furnace gas used as a fuel gas for hot-blast stoves must contain the moisture and dust as low as possible. The so-called water separator (demister, droplets separator) is included in the blast furnace gas cleaning system. To ensure a sufficient efficiency of gas refining, it is necessary to optimize both the separator geometry and the process boundary conditions.
- Understanding the blast furnace gas flow in the separator can be achieved by numerical modelling.
- Since the inlet area was modified in real conditions of the blast furnace plant operation, numerical modelling of the blast furnace gas flow in the separator after treatment was performed. The tangential position of the inlet has led to a tangential flow field that positively affected removal of both dust and excess moisture.

The next stage of the research will focus on the modification of the model network and on the evaluation of the effect of geometry on the efficiency of the separator. In addition to velocity vectors, it will also be desirable to map the efficiency of particle removal also quantitatively by assessing the change in tangential velocity at the monitoring points and the changes in viscosity of the two-phase flow gas-solid particle.

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