Numerical solution of the flow in the gas transfer system of an industrial unit

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ABSTRACT: In this paper, the air flow has been numerically modeled in the production line 4 of Tehran cement factory using CFD. CFD introduces an alternative method to consider the flow behavior in the entire points of this line. Gambit software has been employed in order to draw the geometry of the problem and for grid generation. For modeling, the distribution plates that are positioned before the electrostatic precipitators have been under consideration. In addition, Fluent software has been applied for calculations and numerical solution. Numerical computations for fluid flow have been performed by solving Navier-Stokes equations, coupled with the k-ε turbulence model equations. Velocity and pressure values in various points in the production line 4 of Tehran cement factory have been measured and the required discussions have been made to provide a clear understanding of the case. The impact of distribution plates on the flow behavior can be clearly observed.

Key Words: Cement factory, CFD, DPM, Electrostatic precipitator, Flow distribution, Fluent

INTRODUCTION

only a limited number of researches can be found for the prediction of turbulent flow behavior inside the ESP. Choi et al. (1998) simulated the behavior of charged particles in turbulent gas flow in a 2D model. The other 2D model proposed by Skodras et al. (2006) consists of three wires and two parallel plates arrangements. Bhasker (2011) developed a 3D model to simulate the flow in inlet ducts along with several turning vanes to figure out the flow pattern at the ESP exit position. In the current paper, a real three-dimensional model from the production line 4 has been drawn and the flow has been simulated using this proposed model.

Tehran cement factory was established in 1954 in Tehran. The first production unit of this company was exploited with the capacity of 300 tons per day in 1956. At the present time, the nominal production capacity of Tehran cement factory is estimated at around 12,100 tons per day. In production line 4 of the factory, due to high level of production capacity, three parallel electrostatic precipitators are used to absorb the particles from the furnace. Two of the electrostatic precipitators were made in FLS company added to one more from LURGI company.

It is a very hard task to obtain the flow parameters such as velocity and pressure in the entire points of production line 4 of Tehran cement factory, due to its complex geometry. Moreover, measurement can be applied only in limited points. An appropriate CFD model can play a key role in predicting the flow and optimizing the fluid distribution in this line (Shah et al., 2009).

METHODS

In order to draw the geometry of this line in a three-dimensional format and with real dimensions in Gambit software, the available map of the line in Tehran cement factory was used. In order to draw with higher accuracy, several pictures were taken from different points of the line (Fig. 1). The existing map was drawn in 1977, i.e. about 37 years before. The dimensions of LURGI electrostatic precipitator were measured as follow: 10870 mm (length), 7500 mm (width), and 10500 mm (height). For two other electrostatic precipitators, due to the similarities in the dimensions, similar scales were measured as follow: 10650 mm (length), 7700 mm (width), and 8700 mm (height).
The dimensions of the duct in the route as well as the diameter of chimney were measured from the fan position to the chimney, according to the dimensions given in the map (Fig. 2).

Distribution plates are perforated and are used for uniform flow distribution (Swaminathan et al., 2010). The perforations in these plates are generally circular or quadrangular. When in some parts of the problem geometry, the cross sections become larger or smaller, these plates are utilized. In electrostatic precipitators, these plates are used generally where the flow enters into the electrostatic precipitator and also in the exit point of the flow from electrostatic precipitator into the exit duct. These plates are applied to provide uniform flow distribution inside the electrostatic precipitator chamber.

In this paper, with respect to modeling of the distribution plates used in electrostatic precipitators, after obtaining some information from the factory authorities, it was revealed that three and two distribution plates have been applied in the entry points of LURGI and FLS electrostatic precipitators, respectively.

In order to model these plates in Gambit software, it was assumed that perforations are circular with the radius of 250 mm. For LURGI electrostatic precipitator, three plates (small, medium, large) were considered with the opening ratio (Chen et al., 2008) of (the proportion of the open section’s area to the entire plate’s area) 40, 43, and 51 percent, respectively. Number of the perforations in each of these plates was considered 20, 80, and 204, respectively.

For FLS electrostatic precipitator, two small and large distribution plates with the opening ratio of 48 and 47 percent were considered. Number of the perforations in each plate was considered equal to 108 and 132, respectively (Fig. 3).
For grid generation, the Tetra/Hybrid elements with TGrid type were used. According to the real and large dimensions of the problem, the size of each edge of the elements was considered 500 mm. For perforations of distribution plates, this size was reduced to 200 mm (Fig. 4).

**Governing equations**

The air has been considered as an incompressible fluid. Steady-state flow can be obtained using the mass conservation equation or the continuity equation:

\[ \nabla \cdot (\rho \mathbf{U}) = 0 \]

And the momentum equation:
In the above formula, $P$ is the static pressure and $g$ is the gravity force.

In order to model turbulent flow, there are various turbulent models in Fluent software. The model of realizable $k$-$\varepsilon$ was employed for this research, which can be written as follows [9]:

\[
\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_j}(\rho k u_j) = \frac{\partial}{\partial x_j} \left[ \left( \mu + \frac{\mu_t}{\sigma_k} \right) \frac{\partial k}{\partial x_j} \right] + G_k + G_b - \rho \varepsilon - Y_M + s_k
\]

\[
\frac{\partial}{\partial t}(\rho \varepsilon) + \frac{\partial}{\partial x_j}(\rho \varepsilon u_j) = \frac{\partial}{\partial x_j} \left[ \left( \mu + \frac{\mu_t}{\sigma_\varepsilon} \right) \frac{\partial \varepsilon}{\partial x_j} \right] + \rho C_1 S \varepsilon - \rho C_2 \varepsilon - \rho C_2 \frac{\varepsilon^2}{k + \varepsilon} + C_1 \varepsilon \varepsilon + C_2 \varepsilon G_k + s_\varepsilon
\]

Where:

\[C_1 = \max \left(0.43 \frac{\eta}{\eta + 5}, \eta = \frac{k}{\varepsilon}, S = \sqrt{2 \rho_S S_{ij}} \right)\]

In these equations, $G_k$ represents the generation of turbulence kinetic energy due to the mean velocity gradients, $G_b$ is the generation of turbulence kinetic energy due to buoyancy, and $Y_M$ represents the contribution of the fluctuating dilatation in compressible turbulence to the overall dissipation rate. Each of the above parameters has its special formula to be calculated. $C_2$ and $C_1\varepsilon$ are constant numbers (1.9 and 1.44, respectively).

**Boundary conditions**

The finite volume method has been applied to discretize the partial differential equations and SIMPLE model was used for pressure - velocity coupling and the First Order Upwind method was utilized. Afterwards, pressure-based solver is employed to solve the equations. The time of solving has been considered in steady state. To define the turbulent model in Fluent software, $k$-$\varepsilon$ model and the Realizable type have been used [Shih et al., 1995]. The selected fluid is air.

The boundary condition for velocity inlet was considered according to the components method and in the Cartesian coordinate system, equal to 18 meters per second. The direction of velocity vector was assumed perpendicular to the inlet boundary. Hydraulic diameter was 2.6 meters, which is equal to the diameter of the inlet duct right after the fan. The hydraulic diameter according to the definition for circle is equal to its diameter. The boundary condition for pressure outlet is equal to the atmospheric pressure.

**RESULTS AND DISCUSSION**

In this study, production line 4 of Tehran cement factory was simulated from the fan to the chimney exit in a three-dimensional format. The simulation was performed using two softwares including Gambit and Fluent. This model consists of 953037 cells and 188963 nodes. Simulation was carried out using a computer with the following features: Processing system CORE i3 2.27 GHz, 4 GB RAM, 320 GB memory, and 64-bit operating system (Fig. 5).

![Figure 5. The modeled velocity vectors in Fluent software](image-url)
precipitator. This route starts from the fan (this point is called A) until the end of chimney (this point is called B). In this route, according to its geometry, 14 points have been considered. The second route is the route that passes through FLS electrostatic precipitator. As mentioned previously, in this line of Tehran cement factory, there are two FLS electrostatic precipitators. Due to symmetry in their geometric shapes, FLS electrostatic precipitator has been chosen within the selected route, which is located in the left side of the fan exit. This route starts from the fan (we named this point A) and continues until the end of chimney (this point is called C). In this route, according to its geometry and physical shape and as this route is longer compared with route AB, 16 points were considered (Fig. 6).

![Figure 6. Route AB through LURGI electrostatic precipitator](image)

As apparent in Fig. 7, pressure is reduced when gradually moving down from the fan. This value is relatively constant while moving through LURGI electrostatic precipitator (points 6 to 8) and then, by moving to the chimney, it decreases to reach zero. Thus, it can be concluded that the pressure inside the electrostatic precipitator chamber remains constant when passing through it and the pressure drop is low. In addition, it can be observed...
that while moving through distribution plates (points 5 and 6), the pressure reduces. Hence, distribution plates can lead to pressure drop.

As can be seen in Fig. 8, in this route, the internal pressure of FLS electrostatic precipitator remains nearly constant (points 9 to 11). The physical shape of the problem and the large duct, which is right before electrostatic precipitator, are the major reasons for significant pressure drop (points 5 to 7). The existence of this duct makes the effects of these distribution plates, which are located before the electrostatic precipitator, very low. Now, we study the velocity alterations in these two routes of line 4 of Tehran cement factory. As we already know, velocity is accounted as a vector quantity, which in addition to value has direction as well. Hence, while moving through two routes of AB and AC, due to frequent changes in the movement direction, velocity varies in different directions. In order to defuse this problem, in this case, the resultant value of the velocity has been considered for every point.

As can be watched in Fig. 9, the velocity magnitude in LURGI electrostatic precipitator (points 6 to 8) is very low (about 1 meter per second). The reason is the existence of a horizontal duct before the electrostatic precipitator, which leads to a decrease in the velocity magnitude. In point 5 (i.e. in the end of the horizontal duct), velocity reduces noticeably compared with the beginning of the duct. In fact, it decreases remarkably from 16.3 to 2.9 meters per second. Moreover, the distribution plates before electrostatic precipitator (points 5 and 6) are the other reason for reduction of the gas flow velocity.
As shown in Fig. 10, similar to route AB, the velocity in FLS electrostatic precipitator is very low (i.e. 1 meter per second). Having such a wide duct right before electrostatic precipitator (points 5 to 7), causes a notable reduction in the velocity. In addition, distribution plates before the electrostatic precipitator (points 8 and 9) are the other reason of the reduction in the gas flow velocity.

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