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TWO-DIMENSIONAL COMPUTATIONAL SIMULATION FLOW OF EXHAUST GASES PASSING INSIDE AN ELECTROSTATIC PRECIPITATOR

Giorgos P. Kouropoulos*

Department of Energy Technology, Technological Educational Institute of Athens, Greece

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Abstract: In the present study the two-dimensional computational simulation flow of hot exhaust gases which are passed inside an electrostatic precipitator will be carried out. Initially, the theoretical background and necessary equations from fluid mechanics will be described. These equations will be used by software for flow simulation. Furthermore, are presented the design of precipitator through which the exhaust gases are passed. In the next step follows the declaration of various parameters of simulation on the software and finally the necessary images of the computational simulation for two case studies will be extracted. The general conclusions that arise are that the maximum flow velocity of exhaust gases prevails only at the beginning of the entrance of the precipitation element. There are different velocities in all other parts of precipitation element. When the exhaust gases approach the collecting electrodes within the element, their velocity is decreased.

Keywords: Computational fluid dynamic; computational simulation; electrostatic filter; electrostatic precipitator

* Correspondence to: Giorgos P. Kouropoulos. E-mail: etmecheng@gmail.com

INTRODUCTION

Computational fluid dynamics (CFD) is one important field of fluid mechanics. The CFD deals with determination methods for the physical quantities and parameters that describe the situation of a fluid during the flow circulation into mechanical parts. In the last years the computer usage improved the computational fluid dynamic, thus in each case, the calculation processes became shorter with contribution of a CFD software.

Electrostatic filters retain the solid microparticles using static electricity. There are two categories of electrostatic filters, the filters that static electricity is created by natural way and filters that create static electricity by technical way such as a source of electricity and called electrostatic precipitators. Electrostatic precipitators are used in thermal power stations, industries and factories to remove the emitted pollutants of exhaust gases. Electrostatic precipitators are installed at the outlet place of exhaust pipe and retain ashes and microparticles creating electrostatic field, before the combustion discharge into external atmosphere.

There are an important number of scientists who study the flow situation of a fluid during the filtration process in a filter by using computational fluid dynamic methods, the available mathematical models are known, relevant scientific reports (Sarkhi & Chambers, 2004; Ghiddosi *et al.*, 2006; Shim *et al.*, 2007; Darvishmanesh *et al.*, 2010; Hunter *et al.*, 2013; Keir & Jegatheesan, 2014). There are a few scientific reports about the methods of computational simulation for electrostatic precipitators, relevant reports (Dumont & Mudry, 2001; Feldkamp *et al.*, 2006; Hou *et al.*, 2009; Bhasker, 2011).

KINETIC EQUATIONS OF THE FLUID

The software uses certain equations for simulation. The basic differential equations for two-dimensional computational simulation and determination of flow situation are described below (Abdulnaser, 2009). Navier – Stokes equation is the most important of all. This equation explains the fluid kinetic at the three dimensions x, y, z for compressible flow. The general Navier-Stokes equation is expressed as follows:

$$\rho\left(\frac{\partial u}{\partial t}+\vec{u}\nabla \mathrm{u}\right)=-\frac{\partial P}{\partial x}+\mu\nabla^2+F_x \qquad (1)$$

where:

P: The pressure of gases flow
ρ: The density of gases
t: Time.
u: The speed of gases inside the precipitator.
μ: Absolute viscosity of gases that is depended by temperature.
F_x: The force that moves the fluid at the length of x axes.
∇: Tensor which expresses the fluid kinetic on the three dimensions under the partial derivatives form.

The continuity equation of the fluid:

$$\frac{\partial \rho}{\partial t}=\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}+\frac{\partial(\rho w)}{\partial z} \qquad (2)$$

where:

u, v, w The name of speed vectors at x, y, z dimensions.

The energy equation of the fluid:

$$\rho c_p\left(\frac{\partial T}{\partial t}+\mathrm{u}\,\nabla\mathrm{T}\right)=\Phi+\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right)+ +\frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right)+u\,\nabla P \qquad (3)$$

where:

T: The absolute temperature (K)
Φ: A differential equation

Φ is equal to:

$$\Phi=2\mu\left(\frac{\partial u}{\partial x}\right)^2+2\mu\left(\frac{\partial v}{\partial y}\right)^2+2\mu\left(\frac{\partial w}{\partial z}\right)^2+ +\mu\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)^2+\mu\left(\frac{\partial v}{\partial z}+\frac{\partial w}{\partial y}\right)^2+\mu\left(\frac{\partial w}{\partial x}+\frac{\partial u}{\partial z}\right)^2 -\frac{2\mu}{3}\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right)^3 \qquad (4)$$

Type of the flow and simulation

The differential equations that determine the kind of fluid flow, that is, the calculation of Reynolds number and determination of trends of Reynolds number, are the following:

$$\rho\left(\bar{u}\frac{\partial \bar{u}}{\partial x}+\bar{v}\frac{\partial \bar{u}}{\partial y}\right)= -\frac{\partial \bar{P}}{\partial x}+\frac{\partial}{\partial x}\left[(\mu+\mu_t)\frac{\partial \bar{u}}{\partial x}\right]+\frac{\partial}{\partial y}\left[(\mu+\mu_t)\frac{\partial \bar{u}}{\partial y}\right] \qquad (5)$$

$$\rho\left(\bar{u}\frac{\partial\bar{v}}{\partial x}+\bar{v}\frac{\partial\bar{v}}{\partial y}\right)= -\frac{\partial\bar{P}}{\partial y}+\frac{\partial}{\partial x}\left[(\mu+\mu_t)\frac{\partial\bar{v}}{\partial x}\right]+\frac{\partial}{\partial y}\left[(\mu+\mu_t)\frac{\partial\bar{v}}{\partial y}\right] \quad (6)$$

where:

$\bar{u}$: The average flow velocity.
$\bar{v}$: The average kinematic viscosity of the fluid.
$\bar{P}$: The average flow pressure of the fluid.
μ: The dynamic viscosity.
μ_t: Additional viscosity in the fluid due to internal friction inside an element.

The solution of previous equations for determination of necessary parameters of the flow situation of fluid requires the solution of partial differential equations. There are techniques which help us to solve these equations; some techniques are described below (Kefalas, 2012).

The numerical discretization process. During this process, the factors and coefficients of differential equations are transformed to a numerical proportional. The variables of process can be imported in the software with programming code for finding of requirement solutions. There are three mathematical models that are applied in the software for achieving of numerical discretization, the finite elements method (FEM), the finite differences method (FDM) and the finite volume method (FVM).

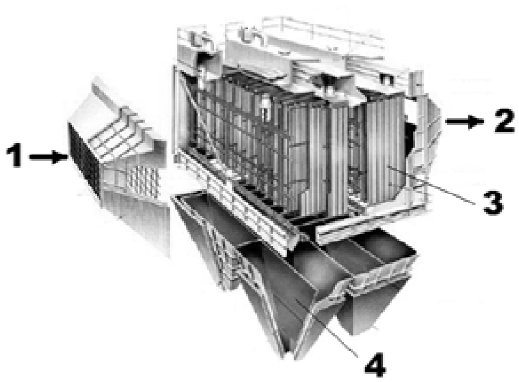
The previous methods present different difficulty degree. The degree varies depending on the simulation case. We usually choose the easier than three methods of computational simulation.

THE INTERIOR OF AN ELECTROSTATIC PRECIPITATOR

Electrostatic precipitator is a complicated system which is comprised of mechanical parts and electronic provisions for controlling electric current that enters to the system and creates static electricity. Also includes additional electronic provisions for insulation and electrocution avoidance. Below is presented the interior of electrostatic precipitator and basic mechanical parts.

Table 1. Technical characteristics of magnetic filter

Parameter	Symbol	Value
Fuel material	-	Oil
Average exhaust gas density	ρ	0.62 kg/m³
Prevailed pressure	P	100 kPa
Exhaust gas temperature	θ	293°C



1. Incoming exhaust gases.
2. Outgoing exhaust gases after dedusting.
3. Electrode arrays or collection plates which retain the solid particles.
4. Collectors for materials that falls from electrodes.

Fig. 1 The interior of a typical electrostatic precipitator.

THE COMPUTATIONAL SIMULATION

(a) Selecting of precipitator element in which intend to become computational simulation.
(b-1) Ground plan design of the specific element and other accessories (**Fig. 2**).
(b-2) Side plan design of the specific element and other accessories (**Fig. 9**).
(c) Insert of drawings in the CFD Software.
(d) Importing of numerical values and parameters settings in the software.
(e) Exporting of computational simulation images for the exhaust gases.

1st case study

In the first case study, will be installed two electrodes per array and there are nine electrode arrays. Hence, there totally are 18 electrodes. **Figure 2** is a ground plan and presents the 18 collecting electrodes for exhaust gases microparticles. The arrows show the direction of exhaust gases flow within the precipitation element.

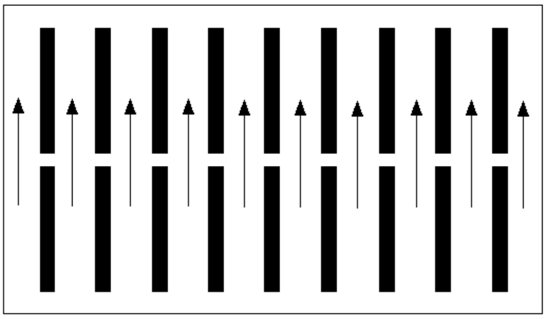
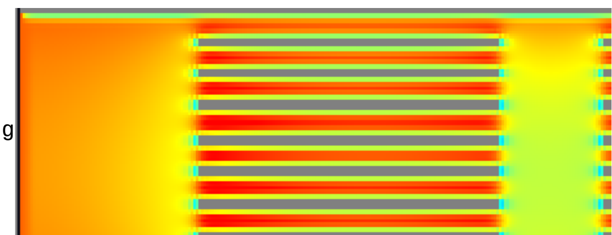


Fig. 2 A ground plan from the element of electrostatic precipitator7.



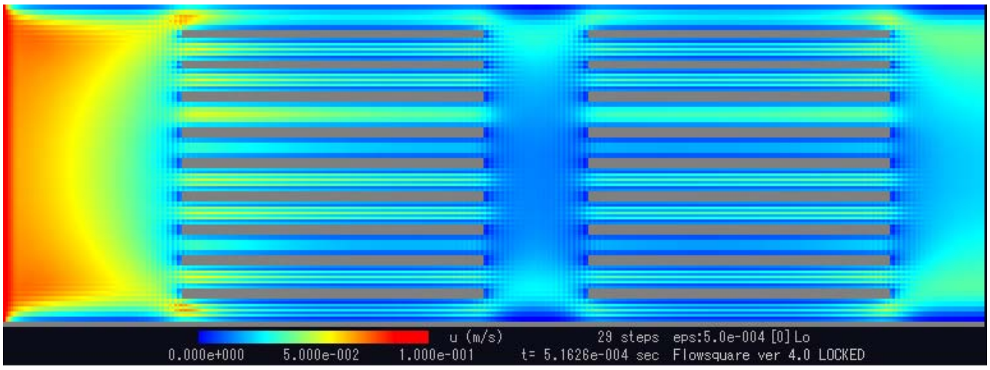


Fig. 4 Simulation image of exhaust gas flow. Initial velocity υ = 0.1 m/s.

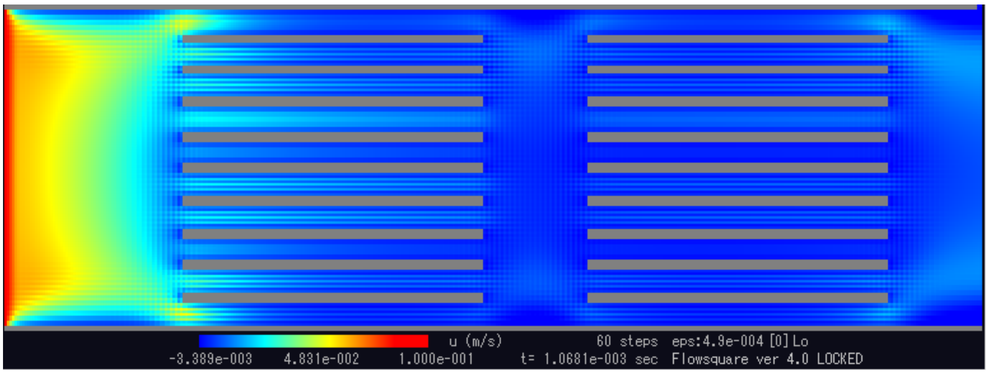


Fig. 5 Simulation image of exhaust gas flow. Initial velocity υ = 0.1 m/s.

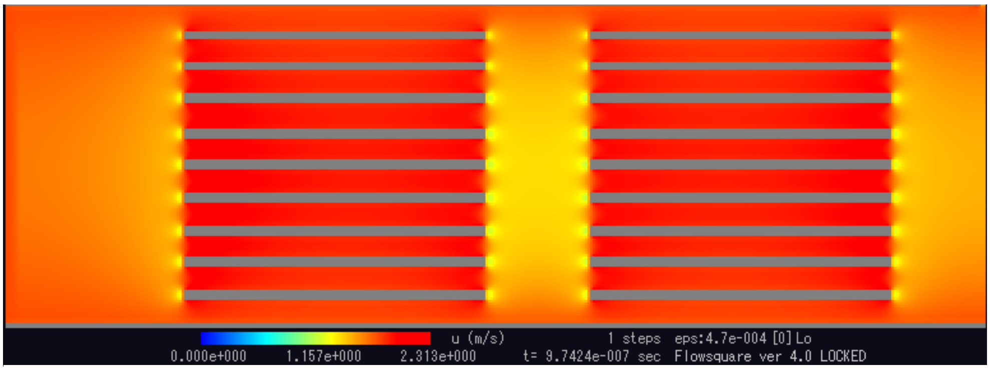
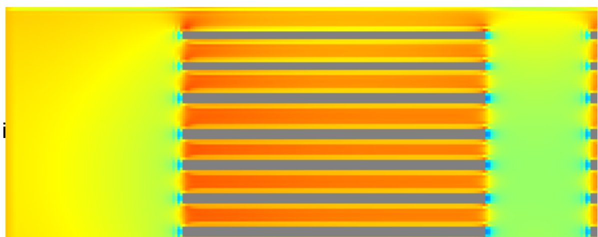


Fig. 6 Simulation image of exhaust gas flow. Initial velocity υ = 2.313 m/s.



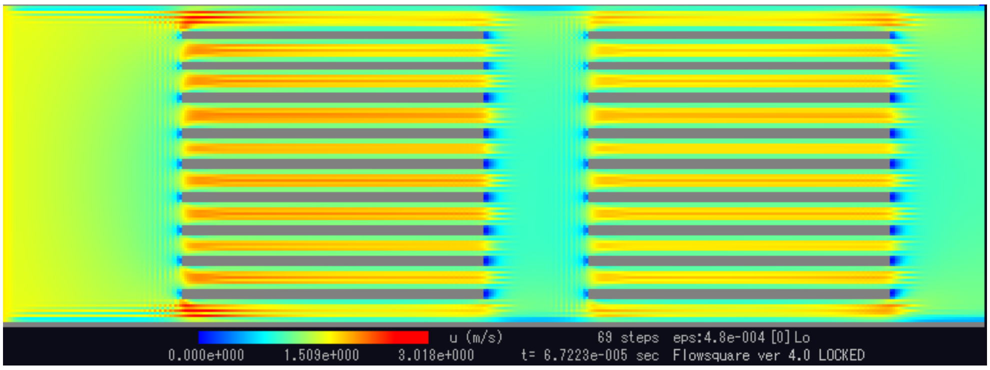


Fig. 8 Simulation image of exhaust gas flow. Initial velocity υ = 3.018 m/s.

If we increase the exhaust gas velocity at the entrance of the precipitation element then velocity increases in the larger part of element.

2^st case study

In the second case, the computational simulation will be executed for a side plan of previous precipitation element with collecting electrodes. This case is necessary because the simulation is 2D and not 3D.

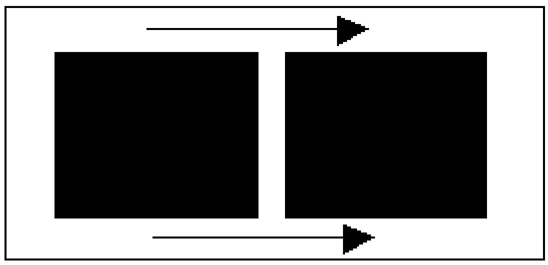


Fig. 9 A side plan from the element on the **(Fig. 2)** of electrostatic precipitator.

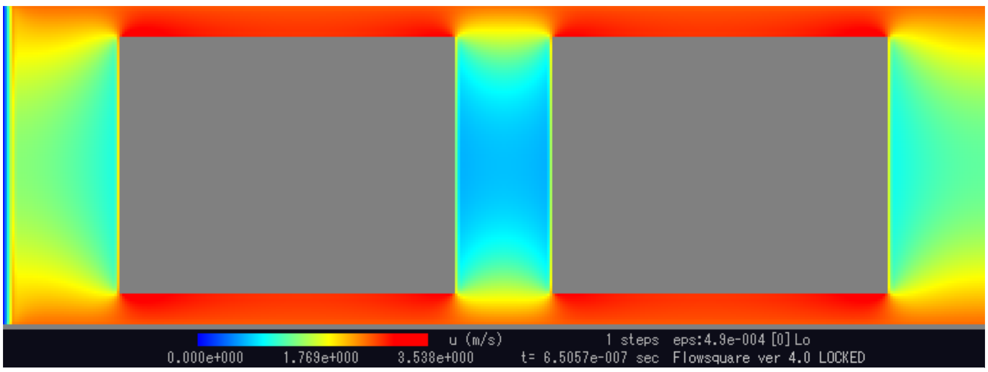


Fig. 10 Simulation image of exhaust gas flow. Initial velocity υ = 3.518 m/s.

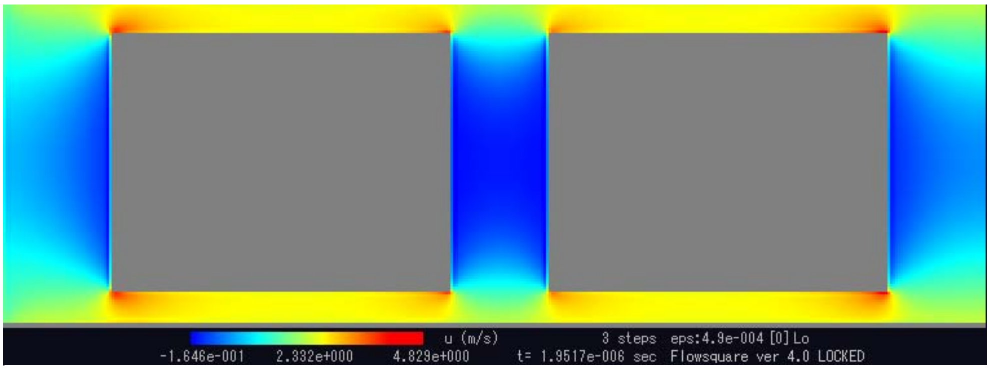


Fig. 11 Simulation image of exhaust gas flow. Initial velocity υ = 4.829 m/s.

CONCLUSIONS

In the **Figs 3–5** we see that the exhaust gases velocity has annihilated in the larger part inside of precipitation element. This probably happens because the velocity of exhaust gases flow within the element has a high friction coefficient on the surface of collection plates with velocity 0.1 m/s. In the next step (**Figs 6– 8**) the flow velocity is increased to 3 m/s.

In the **Figs 6–8** we see that if we increase the exhaust gas velocity at the entrance of the precipitation element, then velocity increases in the larger part of the element. Furthermore, it is too difficult to annihilate the flow velocity. Scientific report of (Hou *et al.*, 2009) confirms that the maximum flow velocity in an electrostatic precipitator, there is always at the entrance of the element.

In the **Figs 10–11** we see that the maximum flow velocity of exhaust gases prevails under and over point of the electrode arrays in compared to other part of the precipitation element. Also, between two arrays, it prevails the minimum flow velocity. In the other hand, at the entrance, the element does not prevail the maximum velocity such as the first case.

Combining the results of two different case studies and taking into consideration the figures from (**Fig. 3**) to (**Fig. 11**), we generally conclude that the maximum flow velocity prevails only at the beginning of the entrance of precipitation element. When the exhaust gases approach the collecting electrodes within the element their velocity is decreased, this is a common result of the two case studies.

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