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Physical and numerical modelling of gas flow in electrostatic precipitator

***Streszczenie.** W artykule przedstawiono wyniki modelowania fizycznego i numerycznego przepływu gazu przez model elektrofiltru, wykonanego w skali 1:20 do istniejącego obiektu. Model fizyczny wykonano z przezroczystego tworzywa w celu wizualizacji przepływu gazu (metodą iskrową). Na podstawie pomiarów rozkładu prędkości w modelu fizycznym, dobrano optymalny układ elementów kierująco-dławiących w celu zapewnienia równomiernego rozpływu gazu w komorze elektrofiltru. Symulacja numeryczna został wykonana w programie Ansys CFX. W pracy dokonano porównania wyników rozkładu prędkości uzyskanych za pomocą modelu fizycznego i numerycznego. (**Modelowanie fizyczne i numeryczne przepływu gazu w elektrofiltrze**)*

***Abstract**. In this paper results of numerical and physical modelling of electrostatic precipitator (ESP) in scale 1:20 to real object were presented. The physical model of ESP was made from transparent plastic to allow visualization of gas flow (by spark method). On the basis of physical modelling gas guiding elements were selected to ensure uniform velocity distribution thought ESP chamber. The numerical simulations were made using Ansys CFX. In this work results of numerical and physical modelling were compared.*

Słowa kluczowe: elektrofiltr, modelowanie fizyczne, modelowanie numeryczne.
Keywords: electrostatic precipitator, physical modelling, numerical modelling.

Introduction

Modern electrostatic precipitators (ESP) are devices of high collection efficiency, which exceeds 99.9 %. A very precision analysis of factors which influence on ESP efficiency is required to achieve that. And one of the most critical parameters is gas flow distribution in ESP chamber. In industrial installations due to space saving, the duct length of the exhaust gas inlet to ESP should be minimized. Too short inlet duct can sometimes generate a non-uniform velocity distribution caused by sudden change in flow direction. In order to improve the velocity distribution, the gas-guiding elements in channels and diffusors are usually installed. At the stage of ESP design, numerical or physical modelling is often used. This paper shows the results comparison of numerical and physical simulations of ESP model in scale 1:20.

Relation between flow distribution and ESP efficiency

Velocity distribution influence in cross-section of the ESP chamber on dust collection efficiency can be calculated using formula proposed by Ideličik and Aleksandrow [1]:

(1) $$\eta = 1 - \exp(-\frac{L \cdot w_t}{h \cdot v_s \cdot M_k})$$

where: η – dust collection efficiency, M_k – Boussinesq's coefficient, L – electric field length, h – inter-electrode spacing, v_s – average gas velocity in ESP chamber, w_t – theoretical migration velocity of dust particle.

Boussinesq's coefficient is a ratio of non-uniformity of the velocity field in the ESP chamber and can be expressed as follows:

(2) $$M_k = \frac{1}{A}\int\left(\frac{v_i}{v_s}\right)^2 dA$$

where: A - cross section area of the ESP chamber, v_i - local gas velocity in measuring section.

Due to the low velocity in ESP chamber (about 1 m/s), the non-uniformity of velocity field has the largest influence on ESP performance [2]. Obtaining a uniform gas flow in ESP chamber ($M_k=1$) is practical impossible and in industrial applications permissible value of Boussinesq's coefficient is $M_k \le 1.2$ [3].

Physical modelling of ESP

The physical modelling is used to improve construction of ESP [4] and involves making of studied unit model. It is important to maintain geometric, kinematic and dynamic similarities. In case of horizontal electrostatic precipitators it is particularly important to preserve the following conditions [2]:

(3) $$\mathrm{Re}' = \mathrm{Re}$$

(4) $$Eu = Eu'$$

where: Re', Eu' – Reynold's and Euler's number in a ESP model, Re, Eu – Reynold's and Euler's number in ESP.

Providing simultaneously equal Reynold's and Euler's numbers in real object and in the model is technically impossible. Thus approximated modelling is applied and based on existence of the self-modelling range. Such range exists with turbulent flow where the following condition is met:

(5) $$Eu = f(\mathrm{Re}) = const$$

This means that the results of velocity distribution and pressure loss measurements in the model can be transferred to the real object reliably. The range of Reynold's number for self-modelling conditions is as follows $\mathrm{Re} \in 10^4 \div 2 \cdot 10^5$ [2].

Description of physical model

Physical model of the studied ESP was developed on the base of the data from real object in compliance with all rules regarding physical modelling. ESP model was made of transparent plastic (SIMOLUX type). The ESP model is shown at Fig. 1. Characteristic parameters of the model are at Table 1.

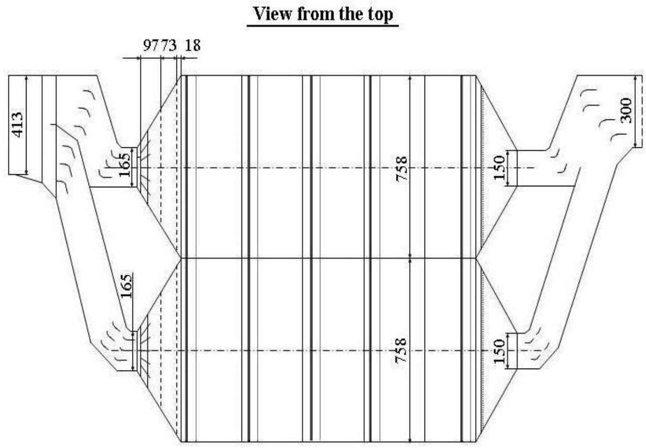
Fig. 1. Physical model of studied ESP

Table. 1. Characteristic parameters of the ESP model

Parameter	Unit	Amount
Model scale	-	1:20
Height of the chamber	m	0.97
Cross-sectional area of the chamber	m^2	1.47
Medium	-	Air
Air flow rate	m^3/h	3260÷3600
Gas velocity in chamber	m/s	0.72
Air temperature	°C	16÷21
Reynold's number for chamber	-	$(3.5 \div 4.8) \times 10^4$
Euler's number	-	2.76

Visualizations of the gas flow in the ESP model were conducted using the spark method [5]. Gas velocity was measured using thermoanemometer with cylindrical probe, of measuring range of 0.10-35 m/s, connected to computer for data registration. Dimensions of a ESP model were shown at Fig. 2.

a)



b)

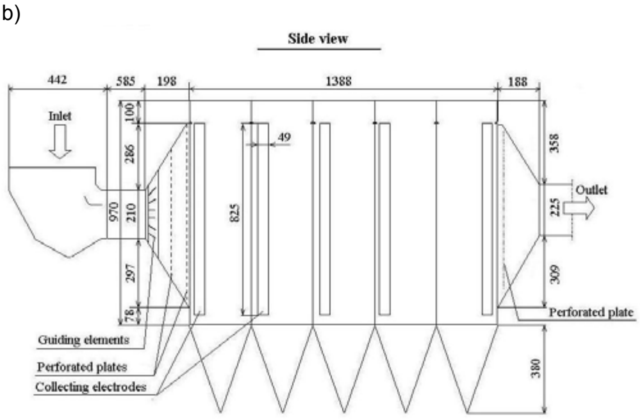


Fig. 2. Dimensions of physical mode of ESP, a) view from the top, b) side view

Use of physical simulation for selection of gas guiding elements

The gas guiding elements were designed in such a way to ensure similar conditions of the gas flow as in real size ESP. The gas velocity measurements were performed in measurement cross section shown at Fig. 3.

Measurement cross section was located after the first row of the collecting electrodes. On the basis of the velocity measurements the changes of gas guiding elements in diffusers were proposed. Gas guiding elements in ESP diffusors before and after changes were shown at Fig. 4.

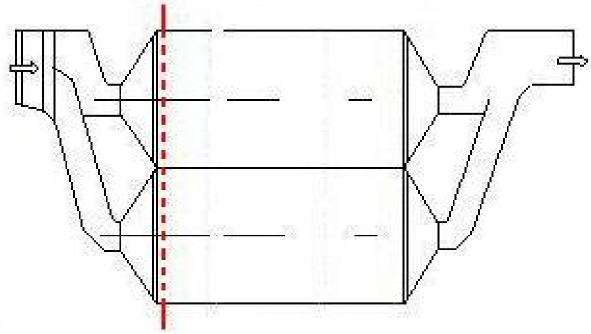
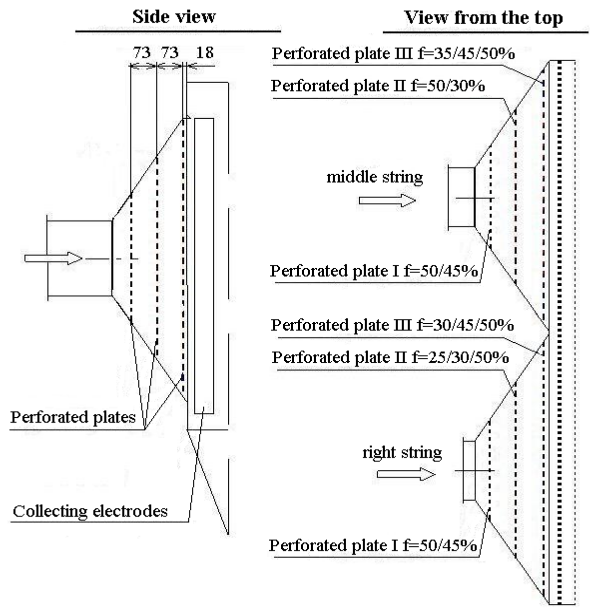


Fig. 3. Measurement cross section

a)



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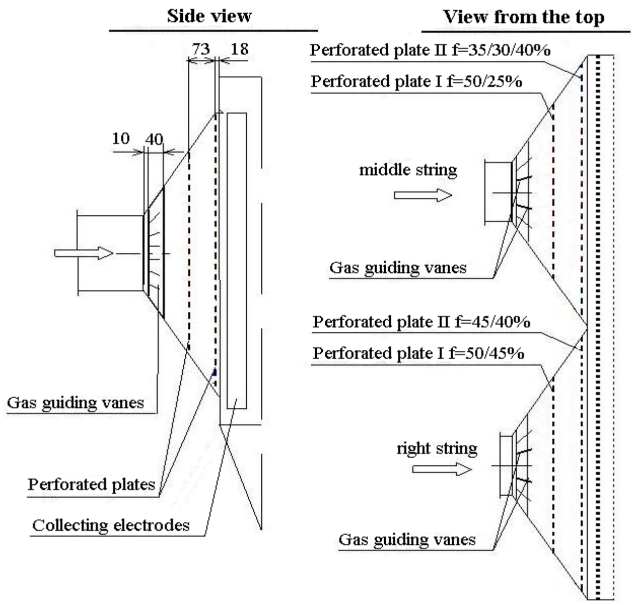
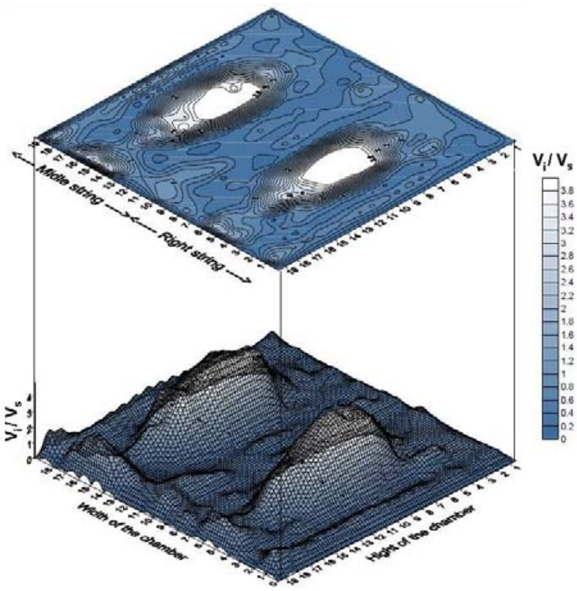


Fig. 4. Gas guiding elements in ESP diffusors; a) before changes; b) after changes

Changes in diffusers were based on replacing first perforated plate with gas guiding vanes. The level of opening the perforated plates number II and III were also changed. The results of gas velocity measurements (as the ratio of measured velocity v_i, to average gas velocity in measurement cross section v_s) for new and old gas guiding elements were shown at Fig. 5.

a)



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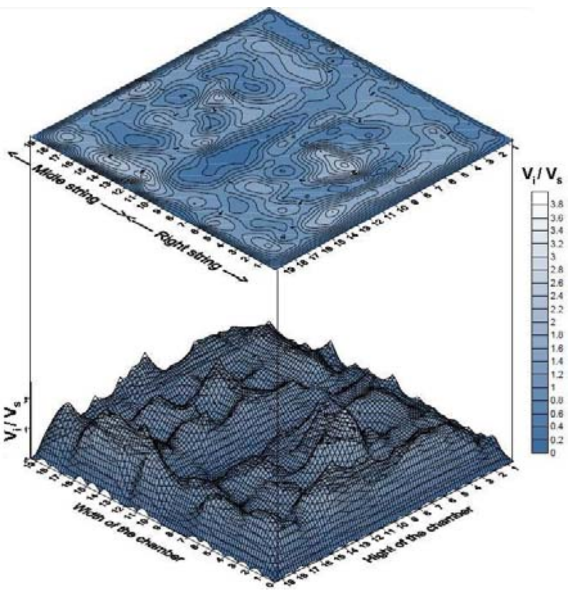


Fig. 5. Results of velocity measurements (361 measurement points); a) gas guiding elements before changes, b) gas guiding elements after changes

The initial gas guiding elements were wrongly selected since the highest value of velocity is 4 times higher than average velocity in measurement cross section. After changes in diffusers the velocity distribution improved. The value of Boussinesq's coefficient for initial gas guiding elements was $M_k=2.06$ and after changes it was $M_k=1.19$.

Description of numerical model

The geometry for numerical modelling was prepared using physical model with the gas guiding elements in diffusers shown at Fig. 4b. Geometry of numerical model was prepared in programme Solid Edge ST4. As part of the simulation, the geometry of air ducts, diffusors with gas guiding elements and initial part of the chamber with first row of collecting electrodes were mapped. The flow parameters for the numerical modelling were well known due to physical modelling. Numerical simulations were prepared in Ansys CFX 14.5 [6]. Basic parameters of the simulation and numerical model were shown in Table 2.

Table. 2. Basic parameters of the simulation and numerical model

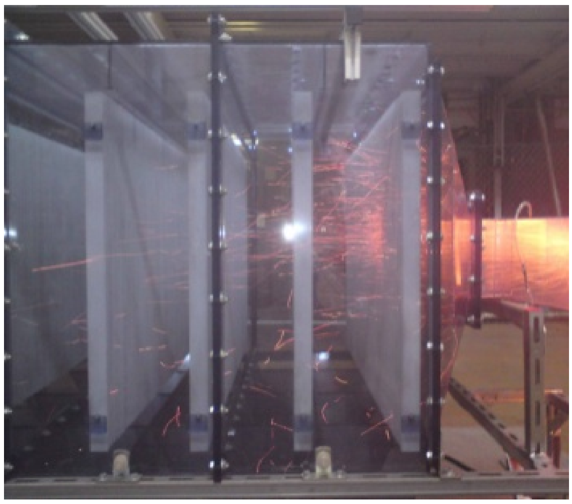
Parameter	Unit	Amount
Number of mesh elements	-	About 5 500 000
Turbulence model	-	k-ε
ESP chamber dimension	m	0.97 x 1.51
Medium	-	Air
Initial velocity	m/s	6.05

Comparison of simulation results

Character of gas flow in numerical simulation and physical modelling is similar (see Fig. 6 and 7). Applying guiding elements, selected on the basis of physical modelling, allows to calculate value of Boussinesq's coefficient in ESP chamber $M_k=1.19$. In case of numerical simulation this coefficient for the same gas guiding elements is $M_k=1.22$.

There were some differences in gas velocity distribution at cross-section of the ESP chamber for physical and numerical modelling (shown at Fig. 8). These differences could be caused by simplification of the model geometry for simulation purposes.

a)



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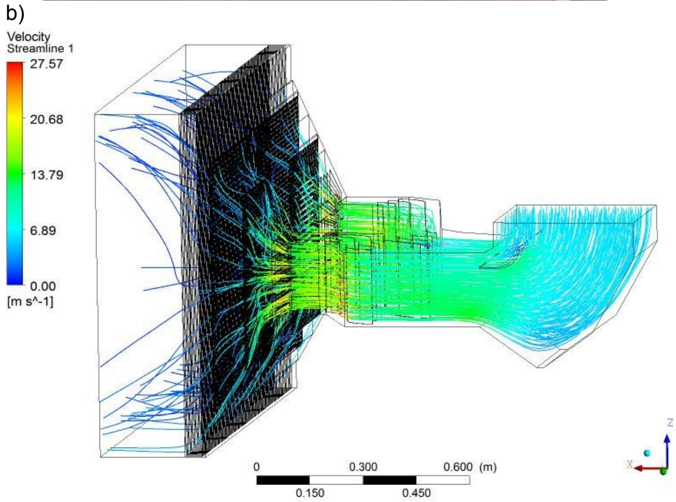

Fig. 6. Visualizations of the gas flow in ESP chamber model; a) physical modelling; b) numerical modelling

a) b)

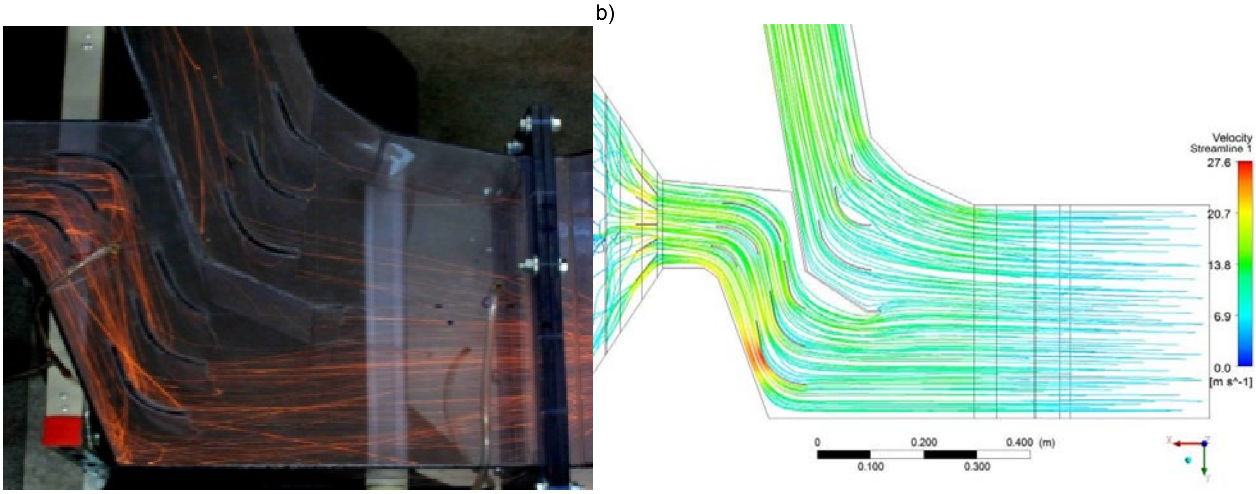

Fig. 7. Visualizations of the gas flow in the duct at the inlet to ESP model; a) physical modelling; b) numerical modelling

a) b)

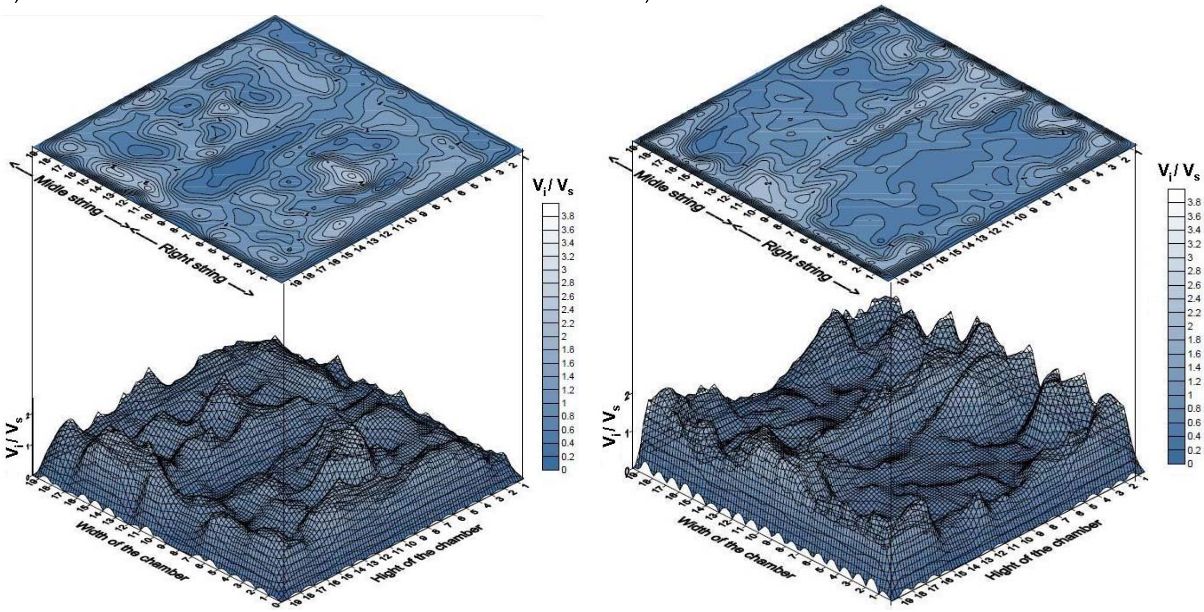

Fig. 8. Velocity distribution at cross-section of ESP chamber (after the first row of collecting electrodes); a) physical modelling; b) numerical modelling

Summary

The changes of gas guiding elements effect better gas distribution in ESP chamber, and have influence on collection efficiency. The streamlines of the gas flow in numerical simulation correspond with the physical model visualization. Some differences appeared in the velocity profile in the cross section after first row of collecting electrodes (Fig. 6), what could be caused by simplification of the geometry for simulation purposes. Main advantage of numerical simulation is relatively short time needed for its preparation. To prepare correct simulation detailed data about gas flow are needed (for example initial velocity field to ESP diffusers). In the industrial application this data often is difficult to find. For that purposes the numerical simulation can be used to preliminary choose of gas guiding elements in channels and diffusers, final verification should be done by physical model.

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