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# OPTIMIZATION OF THE ELECTROSTATIC PRECIPITATORS IN UNIT A1 OF THE KOSTOLAC A THERMAL POWER PLANT

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**Abstract**
*The plate-wire electrostatic precipitator (ESP) achieves maximum efficiency by simultaneously generating the maximum spark voltage via a homogeneous velocity field of the flue gas between the plates. The consortium, consisting of the Vinča Institute of nuclear sciences and the Nikola Tesla Electrotechnical Institute, has successfully developed and applied new measuring equipment and the original methodology for diagnosing the actual working conditions and optimization of the ESP. This paper presents the results of testing and optimization of the ESP of the Kostolac A thermal power plant unit A1. Based on the results of measurements of particulate emissions, flue gas velocity distribution in the flue ducts and chambers of the ESP, the reconstruction of the mechanical turning and damping elements of the ESP and the installation of new power control elements have been proposed. The effectiveness of the proposed measures can be seen in the improvement of the homogeneity parameters of the velocity distribution in the vertical cross-sections in the front of the first and behind the last electric field of the electrostatic precipitator.*

***Keywords**: electrostatic precipitator, particulate emission, on site measurements, CFD*

## 1. INTRODUCTION

Between 2004 and 2022, all 15 units of the Joint stock company ‘’Elektroprivreda Srbije’’ (EPS) system underwent ESP refurbishment and modernization, with an investment of €97 million, reducing particulate emissions from 66,626 t in 2003 to 6,344 t in 2022. Unit 1 of TPP Kostolac A later exceeded the emission limit values (ELV) due to equipment aging, failures of the electrical fields of the high-voltage supply systems, etc. If we take the coefficient of variation $CV = S_{tdev} / v_{ave}$ as the measure of homogeneity of the flue gas flow in the vertical cross-section of the ESP, where $S_{tdev}$ is standard deviation and $v_{ave}$ average velocity, than the Matts-Öhnfeldt generalized form of the ordinary Deutsch-Anderson equation indicate that maximum theoretical ESP collection efficiency results from perfectly uniform gas velocity distribution over the ESP’s chamber cross section [1].

Also, the dust removal efficiency depends on the intensity of the electric field in the ESP chamber. If present the dust removal efficiency by using the power density of the corona, $P/Q\,[W/1000\cdot m^3/h]$, then high efficiency could be obtained only for high values of $P/Q$ [2].

Therefore, a high dust removal efficiency of ESP is achieved by simultaneously establishing a homogeneous flue gas velocity field through the optimally regulated electric field inside ESP.

Vinča Institute of nuclear sciences has been successfully developed and applied new measurement equipment [3] for determination of the velocity distribution in large vertical cross section of the ESP chamber (15 m x 15 m). In consortium with Nikola Tesla Institute of Electrical Engineering an original methodology for diagnosing the working conditions of the ESP have been developed and applied. The methodology consists of: ***inspection*** of the electrical and mechanical equipment of the ESP; ***on-site measurements*** of the flue gas velocity distribution, temperature and composition in the flue gas ducts, particulate matter emissions, homogeinity of air velocity in vertical cross-sections of the ESP chamber, and laboratory analyses of coal, fly ash and bottom ash; ***CFD simulations*** of numerical models with various geometric solutions of the structural elements of the ESP and ***numerical simulation of the electrical parameters*** of various ESP power supply solutions. The results of application of this methodology on optimization of the ESP of unit TEKO A1 are presented in this paper.

For assesing flow homogeinity we have used the dimensionless momentum $M_k$ and energy correction coefficient $N_k$ [4]:

$$M_k = \frac{\int v^2 dA}{v_{avg}^2 A_{tot}} = \frac{1}{A_{tot}} \sum_{i=1}^{n} \left( \frac{v_i}{v_{avg}} \right)^2 \Delta A_i, \qquad N_k = \frac{\int v^3 dA}{v_{avg}^3 A_{tot}} = \frac{1}{A_{tot}} \sum_{i=1}^{n} \left( \frac{v_i}{v_{avg}} \right)^2 \Delta A_i$$

where $v_i$ [m/s] is a mean velocity through the elementary surface *i* of the cross-section of the ESP chamber, $v_{avg}$ [m/s] – mean velocity in the cross-section, $\Delta A_i$ [m$^2$] – elementary surface and *n* – number of elementary surfaces in the cross-section of the ESP chamber. The values of $M_k$ and $N_k$ are equal to unity only under the uniform flow conditions. The additional two criteria used to assess the flow homogeneity is that the area of all fields where the measured velocity is greater than $1.15 \cdot v_{avg}$ must be $\leq 25\%$ of the measuring cross-section area, e.g. $v_{avg\ >115\%} \leq 25\%$ and where the measured velocity is lower than $0.85 \cdot v_{avg}$ must be $\leq 25\%$ of the measuring cross-section area, e.g. $v_{avg\ <85\%} \leq 25\%$ [5].

The ESP of the TEKO A1 unit is the only ESP within EPS in which all gas passages are 500 mm wide. The maximum design value of the effective migration velocity is $\omega = 0.2456$ m/s. This ESP has relatively small specific surface area of the deposition electrodes $SCA = 29.2$ m$^2$/(m$^3$/s), with maximum design values of the specific corona current of 0.593 mA/m$^2$. The corona current values of ESP of unit TEKO A1 in all electrical fields were below the design value of 1250 mA, especially in zones 1 and 2, the temperature and oxygen content in the flue gas were above the design values, while the flue gas flow and the concentration of PM at the entrance to the ESP was around the design value. The flue gas channels and the elbow with set of turning vanes in the front of the ESP diffuser are correctly designed so the conditions for the occurrence of erosion are completely eliminated. In the confusor at the ESP chamber exit, no distribution plate was originally designed or installed.

## 2. EXPERIMENTAL

The velocity measurements in the vertical cross-section of the ESP chamber in the front of the first electrical field indicate that there are two zones with increased velocities in both chambers [6]. One zone is near the centre of the section, closer to the left wall, and the other occupies almost the entire centre of the right half of the section. The velocities at the top and bottom of the cross-sections are at the level of the mean of that cross-section. There are zones of very low velocities near the walls and along the height of the left and right half of the cross-section.

The velocity measurements in the vertical cross-section of the ESP chamber behind the last electrical field indicated that there is a large zone of increased velocities in the centre of the cross-section towards the ceiling of the chamber, while in the lower third of the cross-section and in the upper corners the velocities are well below the average value of the cross-sectional velocity. This distribution of velocities is a direct consequence of the suction effect of the exit from the confusor

and extends through the third and partly through the second electrical zone. It has a very unfavourable effect on dedusting efficiency in these zones. The most of the particles are carried away by the high velocity flow because it does not give the ash particles enough time to charge and separate on the collecting electrodes. On the other hand, there is almost no gas flow and therefore no particle separation in a large part of these electrical zones (Figure 1).

Table 1 presents results of homogeneity evaluation of velocities measured in the vertical cross sections in the front of the first and behind the last electrical field of left / right ESP of unit A1.

*Table 1. Parameters for evaluating the homogeneity of the velocity distribution in the ESP chambers*

| Parameter | $S_{tdev}$ [%] | $M_K$ [-] | $N_K$ [-] | $v_{avg>115\%}$ [%] | $v_{avg<85\%}$ [%] |
|---|---|---|---|---|---|
| **Recommended value** | **≤ 25** | **≤ 1,2** | **≤ 1,8** | **≤ 25** | **≤ 25** |
| **Inlet left ESP** | 34.2 | 1.10 | 1.32 | 32.7 | 36.3 |
| **Inlet right ESP** | 42.4 | 1.10 | 1.44 | 32.0 | 41.2 |
| **Outlet left ESP** | 41.5 | 1.13 | 1.42 | 37.4 | 34.1 |
| **Outlet right ESP** | 44.5 | 1.15 | 1.51 | 33.3 | 43.5 |

The measurement also revealed irregularities in the flows through the flue gas ducts at the entrance to the diffuser, where higher flow rate was measured in the right flue gas duct of the left ESP than in the left flue gas duct. In the case of the right-hand ESP, the flow rate through the left-hand flue gas duct was greater than that through the right-hand duct. This non-uniformity is also reflected in the homogeneity of the flow rate through the ESP chamber.

## 3. RESULTS AND DISCUSSION

From Table 1 we can see that the condition for the parameter $S_{tdev}$ is not fulfilled in any of the observed sections for both chambers. The values of the parameters $M_k$ and $N_k$ calculated for each of the observed sections are in agreement with the recommendations of the literature [4].
Homogeneity criteria $v_{avg>115\%}$ and $v_{avg<85\%}$ are not fulfilled in any of the observed sections. The series of the CFD numerical simulations for the ESP model with different design of new turning and distribution elements were conducted. To further reduce the increased velocities in the upper zones of the chamber, it is proposed to install a distribution grid in the confusor with 16 horizontal panels, 300 mm wide, 9 m span and a vertical distance of 300 mm.

Results of CFD numerical simulation of the velocity distribution behind the last electrical field in the numerical model of the left ESP chamber whit new design of distribution grid with 16 horizontal panels in the ESP confusor are presented in Figure 2. Comparing to measured velocity distribution presented on Figure 1, one can notice much better homogeneity in the cross-section behind the last electrical field, influenced by the new distribution grate design. Numerical results also confirmed propagation of this positive influence through the ESP chamber up to the first electrical field.

## 4. CONCLUSION

The CFD analysis of the flow in the ducts and ESP chamber for the existing/original geometry of the turning and damping elements confirms the presence of pronounced velocity unevenness in the entire chamber of ESP of unit TEKO A1 which was also established by detailed measurements. CFD analysis of the flow in the channels and ESP chamber for the newly proposed geometry of the distribution grid in the confusor indicates that it is possible to significantly improve the homogeneity of the velocity field in the chambers (especially in fields 2 and 3) and thus increase the dedusting efficiency of ESP. It is suggested to choose suitable locations in front of the diffuser and to install suitable pressure transducers and thermometers to measure the necessary parameters to equalize the flue gas flow through the ducts.

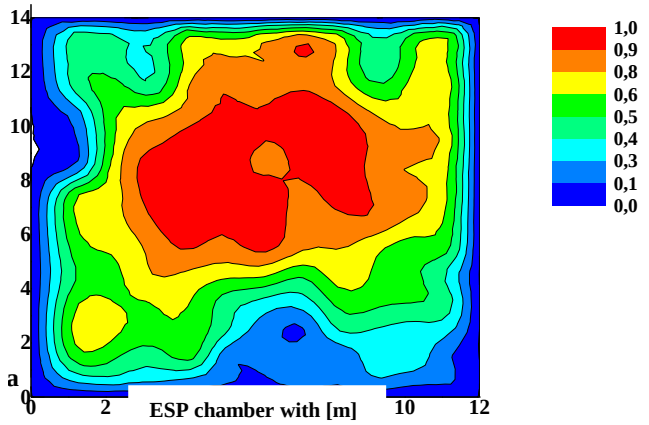



*Figure 1. Measured velocity distribution [m/s] in a vertical cross section behind the last electrical field of the left ESP chamber of unit A1*

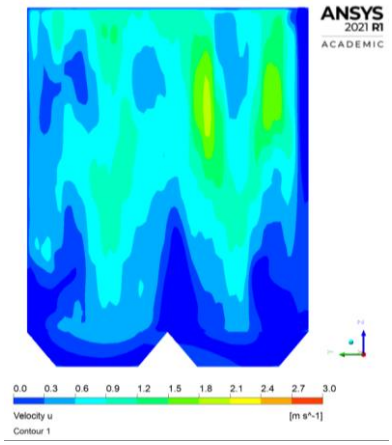



*Figure 2. CFD numerical simulation of velocity distribution [m/s] behind the last electrical field of left ESP chamber whit new proposed design of distribution grid*

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