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ON THE BEHAVIOUR OF THE DUST GAS IN PLATE-TYPE ELECTROSTATIC PRECIPITATOR WITH THREE FIELDS

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ABSTRACT: The purpose of this paper is to analyze the behavior of dust gas in industrial plate–type electrostatic precipitator. The turbulence plays an important role in particles motion and the re-entrainment influence dust particles collection. Also, the turbulence flow of the gases has influence on the fine dust particles, pushing particles away from the collecting plates after the dust particles were collected on the surface electrodes. It is analyze the turbulence and the re-entrainment particles for ESP with three fields from a thermal power station.

KEYWORDS: plate-type electrostatic precipitator, dust particles, turbulence, re-entrainment

❖ INTRODUCTION

A plate-type electrostatic precipitator (ESP) is a device that removes pollutants from the air by an electrical charging process of the dust particles. The unclean gases are passed through a chamber that contains grounded steel plates. These plates divide the chamber into a certain number of parallel channels. In these channels, at the mid-distance between plates, are disposed some discharge conductors, of different shapes in cross-section, sustained by a metallic frame. All the metallic frames from the channels are linked between them, forming a grid. The entire grid is suspended by ceramic insulators which insulate them from electric viewpoint against the grounded parts. Periodical or permanent, the collecting plates and the discharge wires will be rapped. A high-voltage discharge wires create Corona discharge and serve as ions source for dust particles charging. Between the discharge wires and the collecting plates is connected a continuous voltage (the negative potential at the discharge wires). An intense electric field occurs between the discharge wires and the collecting plates. The electric field becomes very intense in the vicinity of the discharge wires in such way that, along the conductors, appear electric discharges by Corona effect. The dust particles migrate and collect to the plates [3].

The phenomenon of turbulence in ESP concerns the time dependent fluctuations in velocity of gas that arise when the flow is non-linear. Small fluctuations in the gas velocity depend of the local flow. Studies provided strong evidence that the turbulence is significantly modulated by the presence of the ionic force created by electric field strength between the electrodes [1,6].

The topic of turbulence in ESPs is too complex, involving multiphase turbulent interactions and electrostatic turbulence production that is poorly understood.

The Reynolds number can be computed with:

$$\mathrm{Re} = \frac{l \cdot v_m}{\nu_c} \tag{1}$$

where l is the total length of ESP, v_m is the mean velocity of the gas, and ν_c is the cinematic viscosity of the gas.

The gas flow through ESP is always turbulent, with $\mathrm{Re} \geq 10^4$ and in input sections with $\mathrm{Re} \approx 10^5$. The turbulence occurs, in the center of gas flow and near the collecting plates, and, generally, near the all obstacle. The quick change of directions and sections are source of turbulence. The velocities of gas near the collecting plates are decrease with 25-40% of mean velocity of gas [2].

The electric wind by ions causes, together with primary flow of the gas, a secondary turbulent flow that affects the overall collection efficiency of the ESP. The secondary flow and induced turbulence is not entirely understood in electrostatic precipitator phenomena. From this reason the turbulence is study by simulating and measuring methods [5,6].

Reducing rapping re-entrainment to an acceptable level generally requires a substantial improvement of the gas velocity distribution and the electrical power density and uniformity, as well as an extended optimization program for the collecting-plate rapping system. Re-entrainment of collected particles is the major contributor to particulate emissions of the precipitator. In some cases, re-entrainment accounts for 60 - 80% of the residual. The major causes of re-entrainment are as follows: particles, voltage controls, design, rapping system, electrical field, and hopper [7].

❖ METHODOLOGY

The ESPVI 4.0.a software (Electrostatic Precipitators V-I Curves and Performance Model) is a prediction model for plate-type electrostatic precipitators. The model prediction shows good agreement with experimental measurements taken at ESPs from U.S.A. under several operation conditions including high resistivity ashes, the use of rectified current and intermittent energization of ESP sections, different size of dust particles (from μm size up to 1000μm), detects the onset of back Corona, peak to average ratio of voltages, different shapes of discharge wires, turbulence and re-entrainment of particles [8]. This software has a lot of plate-type electrostatic precipitators' parameters:

☐ the general electrostatic precipitator parameters;
☐ the electrical electrostatic precipitator parameters for every sections;
☐ the gas parameters;
☐ the dust parameters.

❖ DISCUSSION

It is analyzed the operating of ESPs from a thermal power station, with three sections from Romania. The Thermal Power Station Mintia-Deva has 6 energetic groups each of them has 200 MW. Each energetic group has two large plate-type ESP.

Table 1. The main general characteristics for ESPs with three fields

The main technological characteristics	ESP no.1	ESP no.2	ESP no.3
The sections number	3	3	3
The height of collecting plates (electrodes) [m]	12	12	12
The distance between the collecting plates and the discharge wires [m]	0.3	0.3	0.3
The duct number from sections	54	55	56
The nominal gas stream flow [m_N^3/h]	728900	728900	675000
The inlet dust concentration (from design) [mg/m^3]	85.69	93.61	93.61
The outlet dust concentration (from design) [mg/m^3]	0.75	0.889	0.889
The collecting efficiency [%]	99.12	99.05	99.05
The nominal temperature of inlet gases [^{0}C]	148	148	148
The maximal temperature of inlet gases [^{0}C]	163	163	163
The nominal ashes flow, evacuate from ESP [t/h]	44.5	44.5	44.5
The unburn combustible from ashes [%]	0.3-1.2	0.3-1.2	0.3-1.2
The gas viscosity [kg/(m/s)]	$(1\text{-}5)\cdot 10^{-5}$	$(1\text{-}5)\cdot 10^{-5}$	$(1\text{-}5)\cdot 10^{-5}$
The inferior calorific power of coal [kcal/kg]	2750	2450	2450
The dust resistivity [$\Omega\cdot$cm]	$10^{8}\text{-}10^{13}$	$10^{8}\text{-}10^{13}$	$10^{8}\text{-}10^{13}$

Because the electrostatic precipitators treat large gas flow (600000-700000 m_N^3/h), are dived in three sections and every sections are two fields for reliability, every sections has own electrical supply. The discharge wires dispose in the ducts and are equidistance [4].

It is note with q_i[g/m^3] the inlet dust concentration, and with q_o[g/m^3] the outlet dust concentration for electrostatic precipitators, the ESP collection efficiency η[%] is:

$$\eta = \left(1-\frac{q_o}{q_i}\right)\cdot 100 \tag{2}$$

Table 2. The main electrical characteristics for plate-type electrostatic precipitators supplies

The main electrical characteristics	ESP no.1	ESP no.2	ESP no.3
The supply number [-]	6	6	6
The low voltage supply	2x400 V ±10% 50 Hz	2x400 V ±10% 50 Hz	2x400 V ±10% 50 Hz
The nominal supply current [A]	607	595	595
The ESP peak high voltage [kV]	111	111	111
The ESP nominal high voltage [kV]	65	65	65
The ESP maximal current [mA]	2800	2800	2800
The ESP nominal current [mA]	2000	2000	2000
The apparent power [kVA]	237.2	238	238

The penetration of dust particles through ESP φ[%] is:

$$\varphi = 100 - \eta \tag{3}$$

Factors, such as turbulent factor and re-entrainment factor which can be determined analytically, and must be introduced empirically, are called non-ideal factors. The turbulence factor and re-entrainment factor are important corrections to ESP performance calculations, but the theoretical basis for such values is not strong. The turbulent factor, is a design value and represents a way to deviate from the highly turbulent Deutsch-type collection, which has been the basis for ESP modeling. The turbulent factor describes the number of laminar zones, and generally should have the value 1. To allow for very high turbulence, the turbulent factor should be set to 5 to 10; to allow for very low turbulence, the turbulent factor should be set to 0.25 to 0.5. A higher turbulence in the fields diminishes the overall collecting factors (table 3). In tables 3 and 4 when the fields are rapping, every field (discharge wires and collecting plates) are consecutive rapping for few minutes (10 min.).

Table 3. The ESP performance with turbulence in the fields, and the resistivity $1.7{\cdot}10^8$ [$\Omega{\cdot}$cm] - simulations

Case no.	Field no.	Turbulence factor [-]	The mean diameter of dust particles at input 16 [μm]		The mean diameter of dust particles at input 5 [μm]	
			η with rapping [%]	η without rapping[%]	η with rapping[%]	η without rapping [%]
1	1	0.25	99.16	99.60	95.88	96.76
	2	0.25				
	3	0.25				
2	1	1	98.21	99.35	89.25	92.63
	2	1				
	3	1				
3	1	10	98.07	99.30	88.88	92.37
	2	10				
	3	10				
4	1	0.25	99.16	99.60	95.88	96.76
	2	0.25				
	3	0.25				
5	1	1	98.21	99.35	89.25	92.63
	2	1				
	3	1				
6	1	10	98.07	99.30	88.88	92.37
	2	10				
	3	10				
7	1	0.25	98.2	99.37	89.43	92.75
	2	1				
	3	10				
8	1	10	98.27	99.37	89.66	92.95
	2	1				
	3	0.25				
9	1	10	98.14	99.32	89.15	92.57
	2	1				
	3	1				

Table 4. The ESP performance with different re-entrainment factor and the resistivity is $1.7{\cdot}10^8$ [$\Omega{\cdot}$cm] - simulations

Case no.	Field no.	Re-entrainment factor [-]	The mean diameter of dust particles at input 16 [μm]		The mean diameter of dust particles at input 5 [μm]		The mean diameter of dust particles at input 1 [μm]	
			η with rapping [%]	η without rapping [%]	η with rapping [%]	η without rapping [%]	η with rapping [%]	η without rapping [%]
1	1	0.06	98.96	99.35	91.51	92.65	86.32	87.25
	2	0.06						
	3	0.06						
2	1	0.1	98.51	99.35	90.55	92.65	85.69	87.25
	2	0.1						
	3	0.1						
3	1	0.14	97.86	99.35	89.39	92.65	85.05	87.25
	2	0.14						
	3	0.14						
4	1	0.06	98.58	99.35	90.21	92.65	85.66	87.25
	2	0.1						
	3	0.14						
5	1	0.14	98.5	99.35	90.95	92.65	85.72	87.25
	2	0.1						
	3	0.06						
6	1	0.06	98.74	99.35	90.5	92.65	85.87	87.25
	2	0.06						
	3	0.14						
7	1	0.06	98.75	99.35	91.1	92.65	85.91	87.25
	2	0.14						
	3	0.06						
8	1	0.14	98.66	99.35	91.2	92.65	84.78	87.18
	2	0.06						
	3	0.06						

The re-entrainment factor represents the relative mass of dust that it is re-entrainment in gas flux that is evacuated through the funnel. The re-entrainment phenomenon is produce by the defective rapping of the fields or by design of the fields hoppers. At the ordinary ESPs, in general, the re-entrainment factor has the value 0.1. If the average diameter of the dust particles has small values, the collecting efficiency decreases. The continuous rapping cause the decreasing of collecting efficiency with 1-2%. A higher value of re-entrainment factor (up to 0.14) decreases collecting efficiency with 1-1.5% when the fields are continuous rapping. The domains of the re-entrainment factor is, generally, 0.06-0.14 (table 4).

In fig.1,2, and 3 are present the average diameter of dust particles 16 μm and the ash resistivity $1,7 \cdot 10^8$ Ω·cm, with turbulence factor: 10 for field 1, 1 for field 2, and 1 for field 3. The re-entrainment factor for each field is 0.1.

In fig.1,2,3 where made simulations of collection efficiency, dust particles penetration, and migration velocity when the turbulence is higher in the first field (a possible cause is non uniform gas velocity distribution and/or fault automation – too many electrical discharge in the first fields). The collection efficiency is lower for dust particles with diameter below 5-8 μm when the fields are not rapping, respectively 10-15 μm when the fields are permanently rapped. When the fields are rapping the dust particles under 45μm have low migration velocity.

To assure a laminar gas flux in the duct must be used soft passing of the gas from a section to another section (i.e. from the boiler to the inlet of ESP). Practically, that issue is difficult to achieve. At the input of ESP can be used uniformity devices of the gas flux. Those are made from perforate plates. The perforate plates introduce resistance coefficient in the gas flux. The researchers prove that the uniformity devices must have 8-10 mm thicknesses that involve a lot of material. It can be use another solution with smaller thickness plates (i.e. 2 mm) that has holes with 80^0 bent (holes with X shape). Because the holes are not perpendicular on the plate, in time, the dust will be deposit on them and will be clog. From this reason, in some applications, the uniformity devices must be rapping.

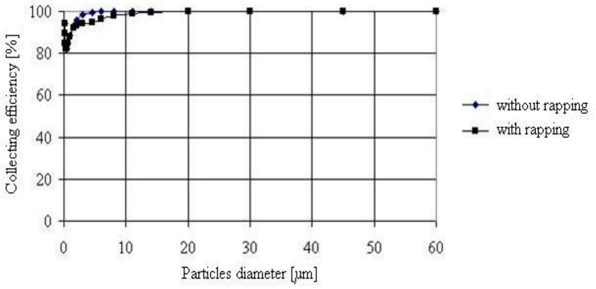

Fig.1. Collecting efficiency depending on dust particles diameter, with and without rapping

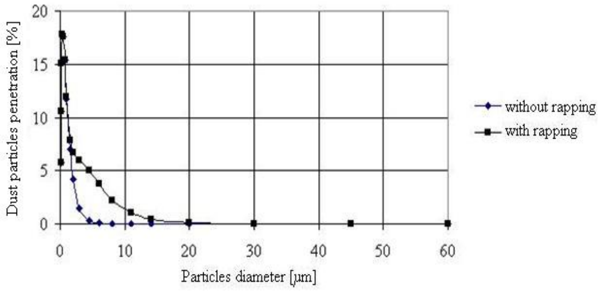

Fig.2. Penetration of dust particles depending on dust particles diameter, with and without rapping

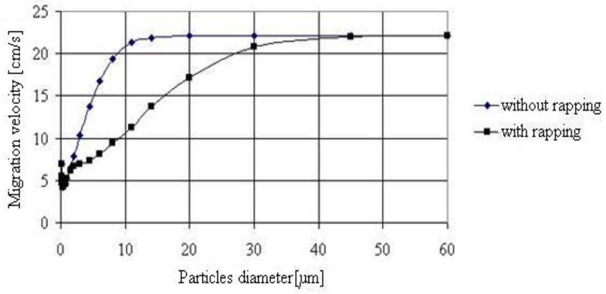

Fig.3. Migration velocity depending on dust particles diameter, with and without rapping

❖ CONCLUSIONS

The collection efficiency electrostatic precipitator depends on turbulence of the gas, on re-entrainment factor, among other factors. The gas distribution of the velocity at the inlet of ESP and the automation of power supplies have an important contribution at gas turbulence. The higher turbulence diminishes the collection efficiency with 1-1.5 %, which is a high value when the gas flow is large. A lower value of the mean particle diameter has an important influence of the collection efficiency (is diminish with 5-7% when the mean particles diameter decrees from 16 μm to 5μm). The re-entrainment factor diminish the overall collecting efficiency of ESP when the rapping is incorrect applied (i.e. in the same time, two consecutive fields are rapping).

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