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ESP MODELLING : FROM UNIVERSITY STUDIES TO INDUSTRIAL APPLICATION

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Abstract:

The need to understand variations in the performance of an electrostatic precipitator, in order to remain in compliance with the regulations whatever coal is burned, leads us to place at the disposal of the operator a user-friendly expert investigation tool based on a complete description of the phenomena involved during the dust collection.
The code used, obtained from much work in universities, calculates the dust collection efficiency per size class, as a function of the inlet velocity distribution and the ESP operating conditions.
Before this code can be used on any industrial site, two actions must be taken : the performance of a "blind" validation test on a 250 MW plant and the reduction of code calculation time to fulfil the operator's requirements.
To test the code, a one-day test was performed on a recently renovated ESP. A limited number of data (gas flow rate, inlet dust concentration and size distribution, ESP geometry, voltage) was provided to permit the efficiency calculation. The values calculated by the software were then compared with the values measured : secondary current intensity, outlet dust concentration and size distribution. The comparison between the calculations and measurements shows a difference of less than 15% for the majority of these variables.

New context for old ESP

In a Power Plant, between producing the initial kWh and finally shutting down the unit, different changes can occur in the operating conditions (coal from different origins, greater air input due to the ageing of the material, installation of low NOx burners, restriction on rates of unburnt carbon in the ashes in order to sell them) or in the regulation (reduction in the limit of dust emissions, restriction of SO_2 and NO_x contents…).

In order to respect to the new dust emissions limit, the operator has several solutions from renovation, often involving large investment costs, to lowering the charge, penalising the viability of the unit.

A compromise consists in studying the origin of the deterioration in performance, then quantifying the effectiveness of several improvements using a user-friendly simulation tool, relying on a comprehensive description of the phenomena occurring when the dust is trapped in an electrofilter : corona effect, electric field, particle charging, migration, collection and evacuation. The model used, derived from numerous university studies carried out by the team of Pr. Gallimberti in collaboration with ENEL [1-5] evaluates the effectiveness of dust capture per granulometric class, taking into account the velocity cartography and the operating conditions of the electrofilter.

The validation of this tool in an industrial configuration has been carried out by means of tests realised under stabilised conditions on a 250 MW unit using a recently retrofitted electrofilter; the input data necessary for the model have been obtained together with the output data, which allows the results of the modelling to be compared to the industrial measurements.

ESP test on a 250 MW unit

The unit selected for the test has a nominal output of 250 MW_{elec} and has an electrostatic dust precipitator comprising 2 parallel casings shown in diagram form in Figure 1. Each casing is equipped with 5 fields, constituting 5 electric sections.
The coal burnt during the test came from Australia, a detailed analysis of the coal and of the ashes is reported in Table 1.

The data collected during the test day can be put into two groups:

1. The model input data :
   - concentration and granulometry of the dust particles entering the electrofilter,
   - composition of the coal,
   - flue gas flow,
   - oxygen and humidity content of the flue gas,
   - flue gas temperature,
   - voltage applied to each field.

2. Measurements to be compared with the results of the calculation:
   - The concentration and granulometry of the dust particles in the flue gas at the output of the electrofilter,
   - The granulometry of the dust particles in each hopper,
   - The current intensity at the transformer secondary in each field.

Some of this information was already available in the control room or on the site (temperature, oxygen content of the flue gas, current intensity and the voltage at the transformer secondary), but some required specific metrological means (concentration and granulometry of the dust particles, flow rate of the flue gas) or sample collection and laboratory analysis (granulometry of the ashes under the hoppers, composition of the coal).

The test was realised with a stabilised 230 MW_{elec} charge using always the same burning coal. The concentration of dust particles was measured outside boiler and exchanger cleaning phases.

During the test, the electrofilter treated a flue gas flow of 10^6 Nm^3/h with a dust load of 13 g/Nm^3 (6% dry O_2) having an average diameter of 11 µm. The flue gas flow entering each one of the two casings are identical.
The measured values of the voltage and current applied to each field are shown in Table 2.
Using the description of the geometry of the electrofilter and the data collected during the test, a calculation was made using the model briefly described below.

Brief description of the self-consistent model

In Italy, I.R.S. in collaboration with Enel and Padova University developed a comprehensive mathematical model for the simulation of the operating conditions of large-scale electrostatic precipitators [2-5]. A self-consistent mathematical model based entirely on the relevant physical laws represents each specific process. This approach enables the calculation of all relevant parameters of a precipitator based only on few input descriptive parameters such as geometry, characteristics of the inlet particles and gas.

The model is time dependent and organized in four sections (Figure 2), which are sequentially executed to calculate space distributions, within a main loop for explicit finite-difference time-integration :

- the first section, independent from the others, contains the gas flow modules: it evaluates under stationary conditions the actual fluid-dynamic conditions of gas motion inside the ESP
- the second section contains the electric field and electric discharge modules: it calculates the electric field and potential distributions with a fast finite-differences Poisson solver and simulates the ionic charge injection into the precipitator volume as a function of time, depending on applied voltage and space charge distribution
- the third section contains the particle charging and migration modules: it calculates the particle charge process taking into account both field and diffusion charging, the ion drift in the electric field and the motion of the particles, using a mixed eulerian and lagrangian approach
- the forth section contains the particle collection, rapping and re-entrainment modules: it simulates the collection and erosion processes occurring at the surface of collecting plates and evaluates the global collection efficiency of the particles, for each granulometric class.

Simulations and measured values

This code was validated on the measurements obtained during the industrial tests described above. The velocity distribution inside the electrostatic precipitator has been analysed by measurements on a reduced scale physical model.

Fluid-dynamic data

The 3D calculation includes computation of the velocities in the input duct (provided with baffles and diffusion grid), the input flare (including baffles and angle deflectors), the five fields of the dust precipitator and the output flare. It was realised using, on the one hand, an adapted version of the FLUENT commercial software and, on the other hand, the N3S software developed by EDF [6,7]. The complex geometry of the assembly, the existence of shutter zones and particularly the presence of numerous grids, not always normalized, made the modelling of the electrostatic precipitator very difficult. The calculated velocity maps were compared to the measurements one realised in the reduced scale physical model.

Figure 3 shows a vertical cross section of the precipitator from the input to the output ducts, which illustrates the calculated horizontal component of the velocity field of the flue gas in the dust precipitator. Figure 4 allows comparison of the horizontal component of the calculated and measured velocities over a vertical cross section.

Electrical data

From the geometrical characteristics of the precipitator and from the applied voltage, the model calculates the intensity of the discharge current.

The experimental read-outs of current and voltage are reported in Figure 5, together with the simulated V-I characteristics (continuous line) for a ambient temperature, no dust, airflow. The difference between the curves of the first field and the others is related to the different plate spacing. The simulation, on average, agrees quite well with the experimental measurements.

Table 2 shows a comparison between the measured and values of the average voltage and current in the real operating condition of the precipitator. For the first three fields, taking into consideration the variations and the measuring errors during the test, the calculated values are very close to the measured statistical values.

The comparison of the current intensity of fields 4 and 5 is less significant because of the current limitation imposed by the control system which could not be taken into account by the modelling.

Particle collection data

a) Particle migration

The behaviour of the particles in an electrofilter depends greatly on their size. Figures 6, 7 and 8 represent the spatial distribution of the particle concentration for three different sizes, calculated by the code, in a section between two collecting plates with two emitting wires. The fine particles (of the order of 1 µm) are charged slowly and weakly, and therefore move slowly towards the collecting plates (Figure 6). The average size particles (of the order of 10 µm) are charged faster and then transported faster to the plate by the electric field (Figure 7). The large particles obtain a large charge in very short time and therefore reach the collecting plates with a very high velocity (Figure 8).

b) Estimation of the efficiency

The efficiency of the dust precipitator was calculated for 9 classes of particle (Table 3), by dividing the precipitator inlet section into 60 channels (Figure 9). The collection efficiency of each channel was simulated for each field, by using the average parallel velocity on the input section of the corresponding channel. The collection efficiency strongly depends on the velocity. Figure 10 shows the input normalized velocity (ratio of the channel velocity to the average velocity on the input section left profile) and the normalized efficiency of a channel (ratio of the channel efficiency to the overall efficiency of the electrofilter right profile).

Figure 11, on the one hand, represents the overall normalized efficiency and, on the other hand, the normalized efficiency for the 9 classes of particles of the dust precipitator as a function of the plates sequence number. Particles with a diameter in excess of 10 µm are immediately trapped by the first collecting plates, whilst finest particles can escape for much more distances.

c) Particle granulometry

Measurements of the ash granulometry were also realised from samples taken from the three hoppers. The first hopper collects the particles trapped by field 1, while the second collects those of fields 2 and 3 and the third those of fields 4 and 5.
The comparison between the measured and the calculated data, Figure 12, shows a correct correlation between simulation and measurement.

d) Comparison of ESP performances

The estimated emissions of dust particles of the initial calculation were lower than the observed ones. In fact, a problem of hopper evacuation was observed, which caused the short circuit of a field of one of the two channels. A second calculation, taking this anomaly into consideration, resulted in a difference between the calculated level of emission and that measured of less than 15%. Therefore, it can be considered that the calculated efficiency is in a good agreement with the experimental measurements.

An industrial vocation code

The test carried out on the electrostatic precipitator of a 250 MW unit, burning Australian coal, has demonstrated the reliability of the modelling, either for the prediction of electrical characteristics, or for the estimation of the overall efficiency of the collection process, by particle class.

A program has been set up to reduce the calculation time and create a user-friendly interface, that will make possible to use this software (which uses only a few validation coefficients) as a tool to help the operation of electrostatic precipitators in industrial applications.

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Humidity	10.9%
Ash (dry)	12.8%
Volatile matter (dry)	31.5%
Chlorine (dry)	0.01%
Fluorine_(dry)	84 mg/kg
Nitrogen (dry)	1.84%
Carbon (dry)	72.20%
Total sulphur (dry)	0.71%
Hydrogen (dry)	4.56%
Lower heating value (LHV) (dry)	6 804
Higher heating value (HHV) (dry)	7 050
Chemical analysis of the ashes	
Silicium (as SiO_2)	53.0%
Aluminium (as Al_2O_3)	24.6%
Iron (as Fe_2O_3)	6.4%
Titane (as TiO_2)	1.5%
Calcium (as CaO)	6.2%
Magnesium (as MgO)	1.7%
Potassium (as K2O)	0.8%
Sodium (as Na2O)	0.3%
Sulphur (as SO3)	3.2%
Lithium (as LiO2)	17 mg/kg

Table1 : Analysis of the Australian coal use during the test

	Measured mean voltage (kV)	Measured intensity (mA)	Simulated intenisty (mA)
Field 1	56 ± 3	220 ± 25	260
Field 2	33 ± 3	285 ± 35	280
Field 3	35.5 ± 5	330 ± 25	300
Field 4	39 ± 3	370*	410
Field 5	38 ± 3	370*	400

*curent limitation due to the automatic control unit

Table 2 : Comparison between the measured intensity and the simulated intensity with the measured mean voltage

Particle class	Mean diameter (µm)	Minimun and maximum of each class(µm)
1	0.8	0 à 1.4
2	2.0	1.4 à 2.8
3	3.6	2.8 à 5.17
4	6.7	5.2 à 12.37
5	18.0	12.4 à 29
6	40.0	29.0 à 55.4
7	70.8	55.4 à 95.2
8	119.6	95.2 à 149.8
9	180.0	149.8 à 590

Table 3 : Class particles definition