THE DESIGN OF ELECTROSTATIC PRECIPITATORS BY USE OF PHYSICAL MODELS

G. Bacchiega, R. Sala, IRS s.r.l. - Italy;
I. Gallimberti, Padova University - Italy
P. Tronville, Politecnico Torino - Italy
F. Zatti, Area Impianti s.p.a. - Italy

ABSTRACT

This paper describes how physical models can be successfully employed in the design of Electrostatic Precipitators (ESP). The development of the computational power of personal computers has made possible the development of mathematical models of complex systems, like ESP, that can be used at relatively low cost. These mathematical models simulate the non linear coupling of the different physical processes inside the ESP: turbulent gas flow, electrical field and discharge phenomena, particle charging and transport, particle collection and re-entrainment.
With the physical models it is possible to avoid empirical correlations, and to optimize the ESP characteristics on the basis of physical and geometrical parameters, taking into account the balance between costs and performances.
In this paper the model characteristics and results will be presented, together with the procedure used in the design of an electrostatic precipitator, to treat the flue gas from an industrial plant. The most critical design characteristics of the precipitator will be discussed.

KEYWORDS

Electrostatic Precipitation, Process Optimisation, Particle Size Distribution, Software

1. Introduction

The design of Electrostatic Precipitators has been mainly based on empirical knowledge of specialized manufacturers. Thanks to the advancements in computer technology and in physical processes description [1], it is now possible to conceive, optimise and design an Electrostatic Precipitator by of use physical models.
The design procedure follows different steps:

- the first step is the draft design: it is based on general specification analysis, expected outlet particle density, site specific physical constraints. To obtain the draft ESP characteristics and dimensions, the Deutsch law and the manufacturer empirical information are mainly used;
- the second step is the physical simulation and optimisation of the gas flow in the ESP collection body: it is realized by placing flow control devices in the inlet and outlet ducts of the ESP;
- the third step is the physical simulation of the particle collection processes, in order to verify the draft design efficiency, and eventually make the necessary modifications to comply the costumer specifications,
- the fourth step is the detailed engineering design and the construction drawings. It includes complete mechanical specifications, cost evaluation and construction scheduling.

In the next chapters this paper will describe the design steps in detail for a real industrial ESP. The software used in the example is an ESP simulation program called ORCHIDEE [2], which includes a 3D fluid-dynamic simulation program called FLUPE [3].

2. Electrostatic precipitator draft design

The design of Electrostatic Precipitators is typically based on customer specifications: they include expected performances under different operating conditions of the industrial process. The design analysis starts from these operating conditions, to choose one or two worst cases: then the main geometrical and electrical characteristics of the ESP are defined by use of simplified collection efficiency calculations, basically derived by the manufacturer empirical measurements and experience.
This paper will illustrate the example of a real industrial Electrostatic Precipitator designed by Area Impianti and IRS for a Glass Factory.
The worst case main operating conditions are reported in table 1: the customer specifications require a particle density at the ESP outlet lower then 30 mg/Nm^3 (dry at 8% of O_2). The particle size distribution is characterised by a double distribution: fine particles from the furnace, and course particles from the process reactions with the additives. The ESP draft characteristics are reported in the second part of table 1.

FLUE GAS OPERATING CONDITIONS		
Gas flow (on wet)	Nm^3/h	124000.
Operating temperature	℃	402.
Operating Pressure	KPa	98.7
O_2 Concentration	%vol	11.25
Relative humidity	%vol	8.7
INLET PARTICLE CHARACTERISTICS		
Particle concentration (dry at 8% O_2)	mg/Nm^3	4707
Furnace particles (average diameter 0.25 micron)	% in weight	4.2
Reaction particles (average diameter 6.0 micron)	% in weight	95.8
DRAFT ESP CHARACTERISTICS		
N° of fields		3
N° of gas passages (d = 400 mm)		19
N° of plates per field (h = 13.35 m, l = 0.5 m)		8
N° of emitting electrodes per plate (RDE type)		1

Table 1 Main operating parameters and draft ESP characteristics.

3. Gas fluid-dynamic simulation and optimisation

Electrostatic Precipitators require almost uniform gas velocity distributions, to collect particles at the highest efficiency. This is realised by placing flow control devices and perforated plates at inlet and outlet of the precipitator.
The position and shape of these devices can be defined and optimised by use of the gas flow fluid-dynamic simulations, and a trial and error procedure.
The 3D simulation software FLUPE [3] uses a multidomain Cartesian PISO algorithm and a two dimensional turbulence model: internal mechanical devices and perforated plates may be inserted in the input file as flow limiting conditions or local pressure drops. A 3D graphic description of the mesh for the case example (about 300 000 non uniform cells) is given in figure 1 left, that includes the cylindrical reaction chamber before ESP inlet. The applied boundary conditions are: uniform velocity at the inlet section, zero pressure at the outlet section, and symmetry condition on the YZ plane at x=0.

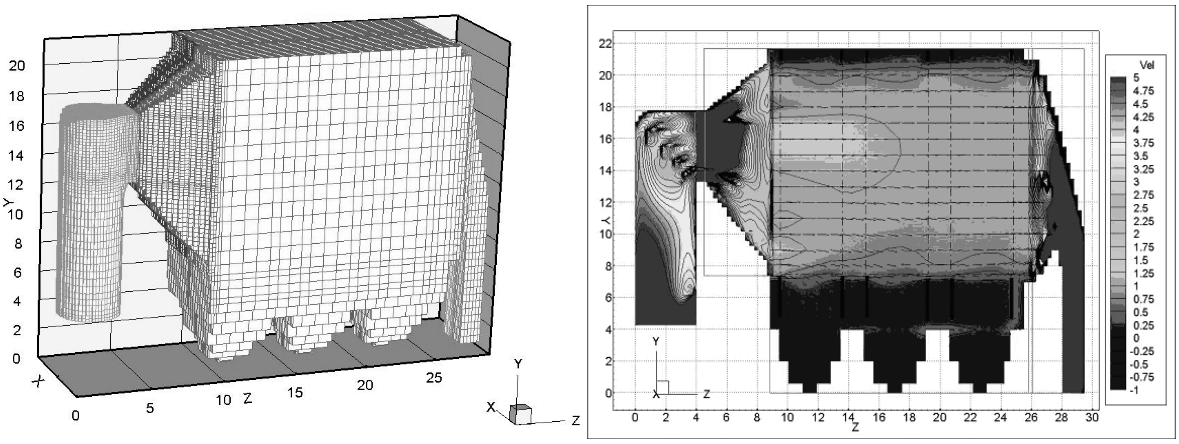

Fig. 1- left) ESP Fluid dynamic 3D mesh;-right) velocity contours (m/s) in the middle section of the ESP (YZ axis)

The computed results are represented as velocity contours, on a side view, in fig.1 right. The optimised flow control devices and the perforated plates (see fig. 2) create an almost uniform velocity region inside the ESP collection body.
The uniformity degree is evaluated by using statistical indexes, as standard deviation and moment of the velocity, in the grid points at the inlet and outlet of each field.

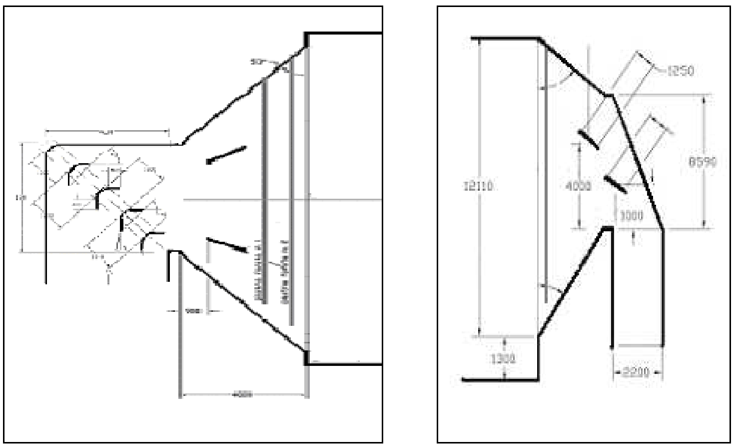

Fig. 2 Flow control devices and perforated plates at the ESP inlet (left) and ESP outlet (right)

4. Particle collection physical simulation and optimisation

The particle collection simulation ORCHIDEE [2] is used to verify the efficiency of the draft design, and to estimate eventual necessary modifications to comply with the customer specifications. The physical models avoid empirical correlations, by solving the strongly non-linear system of differential equations, representing each of the coupled physical phenomena involved in the particle collection:

- Gas flow distribution inside the electrostatic precipitator ;
- Electric field between high voltage electrodes and grounded plates;
- Ion production at the emitting electrodes by corona discharges;
- Migration of negative ions from the ionisation region to the collecting plates;
- Electric particle charging, depending of their size and volume distribution;
- Particle migration under the action of electric, viscous and gravitational forces;
- Particle collection on the plates;
- Plate rapping and particle evacuation into the hoppers.

The first phase of the design simulation process, is the analysis of the electrical ESP characteristics at room temperature, without dust load: under these conditions the current emission capacity of the H.V. electrodes is tested and compared with basic experimental results. In Fig. 3, left, the computed electric field distribution between high voltage electrodes and grounded plates is reported; it includes the negative ion production by corona discharges, and their migration from the ionisation region to the collecting plates. In Fig. 3, right, the corresponding Voltage-Current characteristics are compared with experimental measurements at room temperature, and extrapolated to the operating temperature of 400℃.

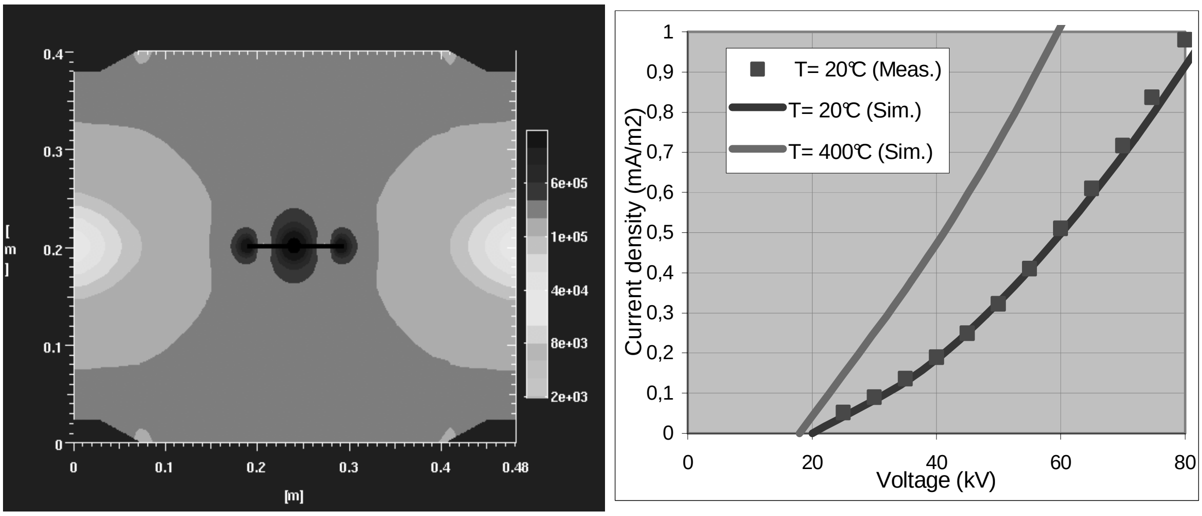

Fig.3 left) Electric field contour in a collection cell;
right) Voltage-Current characteristics at ambient and operating temperature.

The second phase is the simulation of the precipitator under the real operating conditions (flow rate, gas density and composition, dust load, etc) The particles are subdivided in specific mass classes, and treated in any point of the finite difference grid depending on their specific mass and charging process. In Fig 4, left, the particle size distribution used in the simulations is reported, according to the furnace and reaction particle characteristics (see table 1).

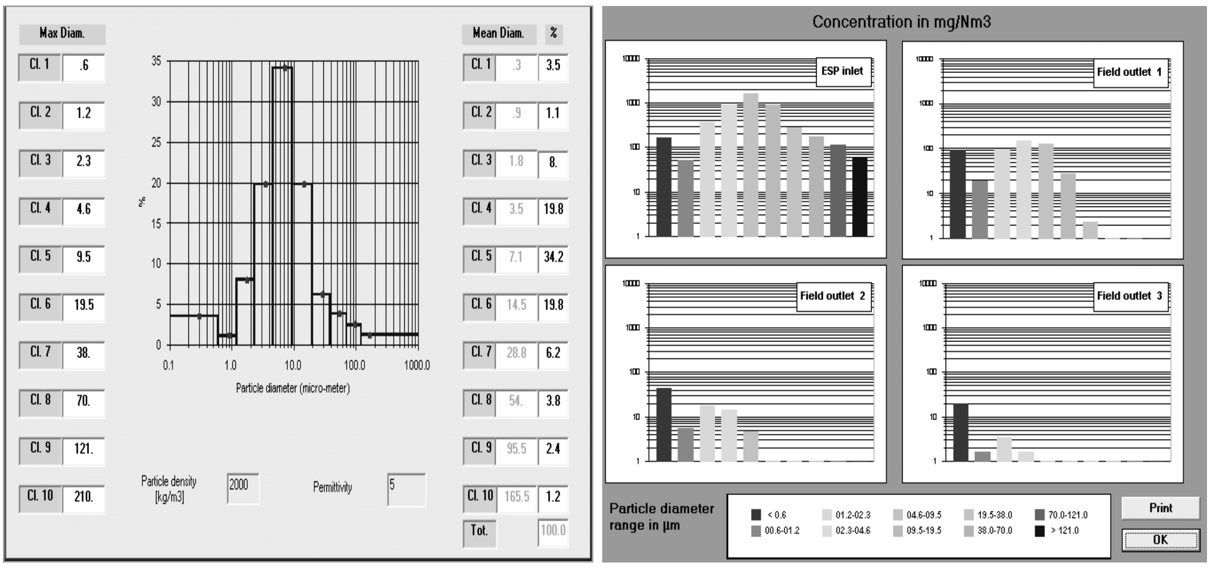

Fig.4 left) Particle size distribution (max diameter, mean diameter and %in mass per class);
right) Size distribution at the inlet and outlet of each ESP field

An example of the simulated results is shown in figure 4, right, which gives the particle density at inlet and outlet of each field, for any of the mass classes. Particle concentrations decrease along each field with an efficiency that depends on their size: the fine particles are more difficult to collect, and therefore survive longer along the precipitator; at the ESP outlet the particles are mainly sub-micron particles.

4. Mechanical and detailed layout

After the particle collection verification and optimisation, the ESP design proceeds to the detailed electrical and mechanical description of the precipitator. The detailed layout drawings will take into account the mechanical sizing, as well as the constraints for construction, security and maintenance of the precipitator (foundations, thermal insulation, internal devices and passages, etc.).
The electrical and mechanical detailed description then allows costs evaluation and constructions scheduling.

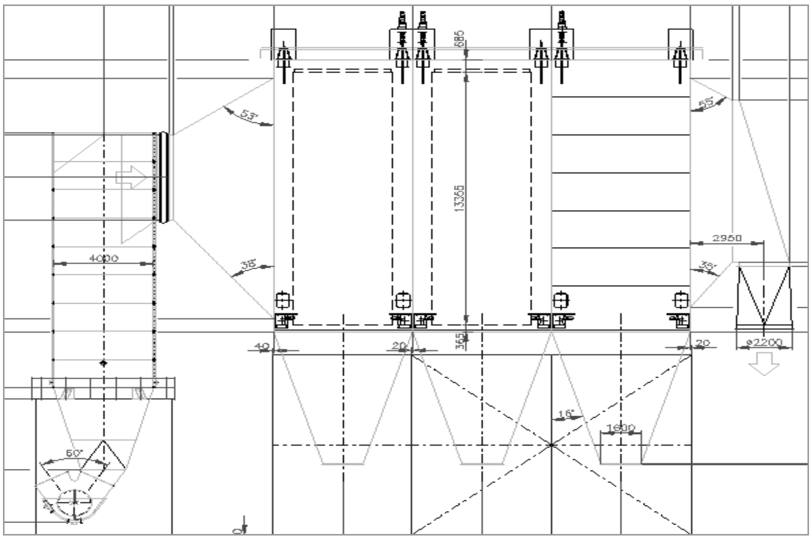

Fig. 5 Mechanical layout

4. Conclusions

The design of electrostatic precipitators can be successfully realized by the use of physical models, to verify and optimize the geometrical and operating parameter of the collection process.

5. References

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