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DEVELOPMENT OF AN INDUSTRIAL MODEL OF RAPPING – EFFECT ON THE COLLECTING EFFICIENCY

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ABSTRACT

The rapping process is not yet well understood for two main reasons : on the one hand the objectives of the research have been focused for many years on a empirical optimisation of rapping, the knowledge of generation and evolution of the layer was considering as less significant, on the other hand the evolution of the dust layer is difficult to reproduce in a laboratory physical model. The experimental study of the mass balance in an industrial esp pilot provided precious data and made the development of the model possible. It has been compared with good agreement with an industrial esp test in a 500MW power plant. The model of rapping plates has been developed and integrated in the new version of the EDF-IRS software ORCHIDEE to help the plant staff to optimise their rapping sequences. ORCHIDEE is a user friendly software and we succeed to integrate the rapping model with only geometrical and operational data like the different times of rapping operation, the variation of these times influences the layer thickness on the plate and finally the collecting efficiency.

INTRODUCTION

The impending European regulations applicable to pulverized coal power plant becomes more and more stringent for the level of dust emission. Emission limits values fixed by the LCP-D (Large Combustion Plant Directive) reach 50 mg/Nm^3 assuming an oxygen content of 6% in the flue gas in the case of solid fuels. This reinforcement implies a fine dust emission control. It is well known that a major key of the optimization of the electrostatic precipitator is the rapping process, rapping have indeed a profound effect on re-entrainment of the collected particles in the flue gas and may increase the emission levels.

The first step to optimize the rapping process is the adjustment of the rotating tumble hammer generally installed in esp. The numerous scientific studies (Parker, 1997) and the supplier experiences focused only on the rapping process and not on the comprehension of the dust layer evolution on the plate.

The second step proposed in this paper is the description of the influence of rapping sequences on the layer and then on the dust concentrations. The experiments performed on a semi-industrial scale provide reliable and complete measurements in the framework of the ABRICOS Project, supported by the European Community. These experiments lead EDF and IRS to develop a simplified model of the dust layer evolution.

This paper describes the theory and the mathematic model implemented in the software ORCHIDEE. The coupling with the widely known physical phenomena involved in the esp process is also tackled to assess the effect on the collecting efficiency. Finally, the result of the ORCHIDEE simulations is compared to industrial data.

1. GENERAL APPROACH

1.1. General consideration on the layer evolution

Some patents may help the operating personnel in optimizing the rapping, this optimization is based on the measured couple voltage – current on the plate (patent US4521223 – WO 9741959).

The optimization of the rapping needs a good knowledge of the layer thickness on the collecting plates. Horrocks and Moore (1996) showed in a pilot similar to Marghera that the re-entrainment of the particles wasn't important until the bulk velocity reach 2 m/s. Then a precise assessment of the re-entrainment as only a function of the layer thickness is the way to follow for EDF ESP.

The thickness of the layer is the result two main phenomena :

- A continuous phenomena,
  - The thickness of the dust layer increase by the electrostatic force, the application of the classical Deutsch law estimates with confidence the efficiency of this process and by the way the corresponding thickness of the dust layer
  - The re-entrainment of the particles in the bulk gas flow by erosion and decrease the thickness

- A discontinuous phenomena,
  - The acceleration given by the hammer during a rapping release a portion of the dust layer and then decrease its thickness.

- The re-entrainment due to the rapping, one class of particles is collected again and the other class stay in the bulk flow gas.

The continuous phenomena is already included in the first version and is determined by a derived Deutsch formula.

This paper focuses on the discontinuous phenomena and describes the approach resulting in the simplified model of rapping and finally implemented in the ORCHIDEE software.

The layer distribution on the plates depends mainly on particle rate attaching to the particle layer at the plate and on the falling particle rate to the hopper, given mainly by rapping. What it is not straightforward is that not all the layer falls into the hopper after a rapping shot.
The particle layer at plates is first modelised by using a mass balance conservation equations and a simplified rapping and layer representation.

Between two rapping the particle rate at plates is considered contant as described by equation (1), while the rapping process is described as following: a portion of particle falls as a single piece and the rest is re-injected in the bulk gas flow as particles, the layer single piece is re-attached after a fall of H_l meter (this value can be estimated based on rapping efficiency, layer height and thickness), while only a percentage of particles is re-attached to the particle layer. The particle re-attach to the layer after a fall which and the re-entrainment rate can be estimated thanks to the lagrangian computation carried out in ABRICOS project by IRS. Using these hypotheses and dividing particle in class as a function of diameter it is possible to estimate the layer thickness of each plate as a function of the rapping time and rapping efficiency.

It is also possible to estimate the re-entrainment caused by rapping.
This model does not include the sliding process pointed out by Marghera hopper weight measurements. Both measurements and a first model of the sliding process show that re-entrainment estimation due to rapping can modify mean ESP efficiency.

1.2. Layer description model, sliding process

The sliding process has been measured by the Marghera experiments. The details of mass entering the ESP and collected at plates and hoppers could determine a continuous fall of particles into the hoppers and an increase of the falling velocity when the current is low (Bacchiega 2005).
As measured falling velocity seems constant when then current is fixed, a viscous force helps to comply to the force balance governing the layer evolution on a vertical axis :

$$P - F_m - F_g = 0 \qquad \text{Eq. } \mathbf{(1)}$$

Where

P : gravity force, $P = r \cdot g \cdot l$

with r the layer mass density, g the gravity acceleration and l the layer thickness.

F_m : friction force, $F_m = m \cdot P_e$

with m is a friction constant (approximatively 0.4 for solid/solid contact), P_e is the electrostatic pressure

F_g : viscous force, $F_g = g \cdot v$

with g the viscous coefficient determined experimentally between 3000 and 4000 N/s in Marghera experiments and v is the vertical falling velocity.

The role of electrostatic pressure is clearly highlighted by Canadas et al. (1996) in the analysis of 52 different coals. They found two major components Na2O and SO3 involved in the cohesion of the particles in the layer : the resistivity of the ash is modified by the presence of these elements and implies a change of the electrostatic force changes. The granulometry is a second order of importance in the cohesion of the layer.

With the electrostatic laws, the electrostatic pressure is given in equation 3 in (N/m²) :

$$P_e = \left(e_0 E_{bulk} - e_1 E_{layer}\right)\frac{\left(E_{bulk} + E_{layer}\right)}{2} \qquad \text{Eq. } \mathbf{(2)}$$

Where

E_{bulk} is the electric field outside the layer and

E_{layer} is the electric field inside the layer, it is given by multiplying current density and ash resistivity.

The layer sliding velocity, the layer thickness and estimated viscous coefficient has been then possible using Marghera pilot plant database (Bacchiega 2005).

2. MATHEMATICAL FORMULATION

2.1. Rapping model : general equation

A balance equation can be written for the layer thickness on a vertical axis :

$$\frac{\partial l(z,t)}{\partial t} + v(z,t)\frac{\partial l(z,t)}{\partial z} = \dot{l}_c - l(z,t)\frac{\partial v(z,t)}{\partial z} \qquad \text{Eq. } \mathbf{(3)}$$

Where

l(z,t) : layer thickness in m,
z : vertical coordinate in m,
t : time in s,
v(z,t) : vertical velocity of the layer in m/s,
$\dot{l}_c$: growth of the layer in m/s.

If the velocity v_z is supposed constant, *i.e.* without rapping, this equation can be integrated on the plate height H_z :

$$\frac{H_z}{v_z}\frac{\partial l(t)}{\partial t} + l(t) = \dot{l}_c \frac{H_z}{v_z} \qquad \text{Eq. } \mathbf{(4)}$$

And the solution is :

$$l(t) = l(0)e^{-t/T_B} + l(\infty)\left(1 - e^{-t/T_B}\right) \qquad \text{Eq. } \mathbf{(5)}$$

With :

$$l(\infty) = \frac{\dot{l}_c H_z}{v_z} \text{ and } T_B = \frac{H_z}{v_z} \qquad \text{Eq. } \mathbf{(6)}$$

The equation **(5)** can also be used with rapping by considering that the velocity is averaged between two raps on the same plate, this velocity is now estimated:

$$v = \frac{H_d}{\Delta T}$$

With

H_d : distance of the layer drop in m

ΔT : time between two raps in s

Then :

$$l(\infty) = \frac{\dot{l}_c \, \Delta T \, H_z}{H_d} \text{ and } T_B = \frac{H_z \, \Delta T}{H_d} \qquad \text{Eq. } \mathbf{(7)}$$

Both solutions can be coupled, considering that the velocity is constituted by the continuous sliding velocity v_s and the velocity v averaged between two raps :

Then :

$$l(\infty) = \dot{l}_c \, H_z \left(\frac{\Delta T}{H_d} + \frac{1}{v_s} \right) \text{ and } T_B = \frac{H_z}{v_s + \frac{H_d}{\Delta T}} \qquad \text{Eq. } \mathbf{(8)}$$

Relation **(8)** needs the value of the sliding velocity, it depends on weight force and then on the layer thickness. An iterative procedure is necessary to find the solution or a constant height equivalent to the mean distance of the fall.

The layer evolution has been also modelised with more complicated assumptions and longer computations, the acceleration has been taken in two forms, uniform and non-linear. Unfortunately the measurements related to these assumptions aren't reliable enough to use such models and are difficult to assess in a industrial context.

2.2. ORCHIDEE development

The relation **(7)** has been finally used for its simple formulation and the fewer hypothesis : the distance of the layer drop H_d is estimated around 2 m. The electrical field inside the dust layer can be calculated as soon as the thickness layer is determined by relation **(7)**, then the available voltage of the dust collection is calculated and is taken into account in the efficiency of the esp.

The input data of ORCHIDEE 2 relative to the rapping module are :

t_a : time during a complete rotation of the drive shaft in a continuous mode (*i.e.* without pause) in s.

A : Angle between two successive rappers

t_m : time of motor work in s

t_p : time of motor pause in s

These data enable the estimation of the ΔT parameter :

$\Delta T = t_a \cdot \frac{t_m}{(t_m + t_p)}$, ΔT represents finally the time for a cycle of the drive shaft to make a complete rotation in a discontinuous mode (with pauses).

S : number of rappers hitting a plate simultaneously

N : number of rows in a casing, (N +1) is the total number of rappers on the drive shaft.

$$S = \frac{N+1}{360°/A}$$

These data have been fitted with the frequency of the peak dust emission observed at the esp exit in Marghera measurements.

Measurements have also showed that the rapping efficiency and the re-entrainment of the particles depend on the thickness of the dust layer. This value have never been established but the measurements enable to give some reasonable estimations. A re-entrainment coefficient already exists in the physical model of particles motion and is function to the diameter of the particles and independent to the thickness of the layer. The relation between the thickness layer and an additional coefficient of re-entrainment has been established from the database of Marghera measurements in the frame of European project ABRICOS. This evolution of the coefficient is shown in figure X, the zero values, between 0.3 mm and 0.8 mm, mean that the thickness is optimal and generate the fewer re-entrainment. ORHIDEE 2 estimates the the efficiency of the esp by considering the thickness layer and the related re-entrainment.

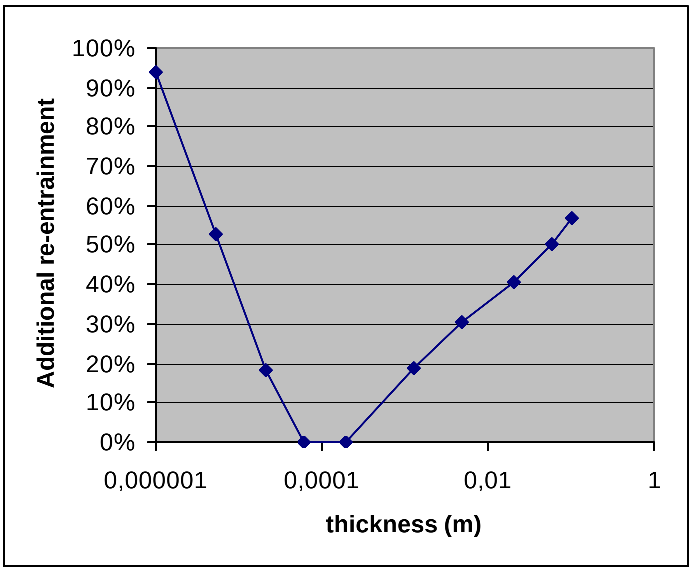

Figure 1 : Additional re-entrainment versus thickness

3. COUPLING WITH GENERAL PHENOMENA AND RESULTS

3.1. Coupling scheme

The rapping module is a part of a computation scheme where the esp efficiency is the result of a non-linear coupling between several process (***Figure 2***). The red arrows indicate an iterative procedure to make the layer effect converge. The first iteration starts with a zero thickness, all the tests indicate that two or three iterations are sufficient. Further details relative to the others modules are given by V. Arrondel and al. (2006).

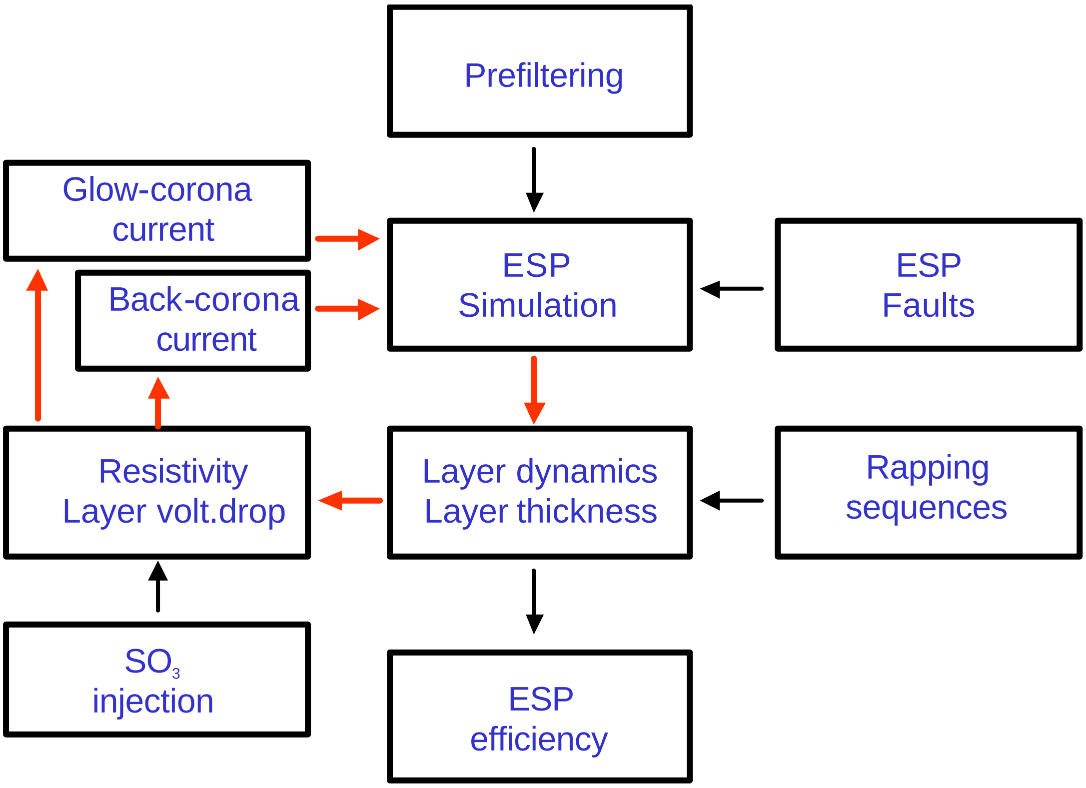

Figure 2 : Non-linear coupling between the different physical process in ORCHIDEE 2.

3.2. Influence on the thickness layer

In ORCHIDEE 2, the rapping module presents input data field by field (Figure 4)

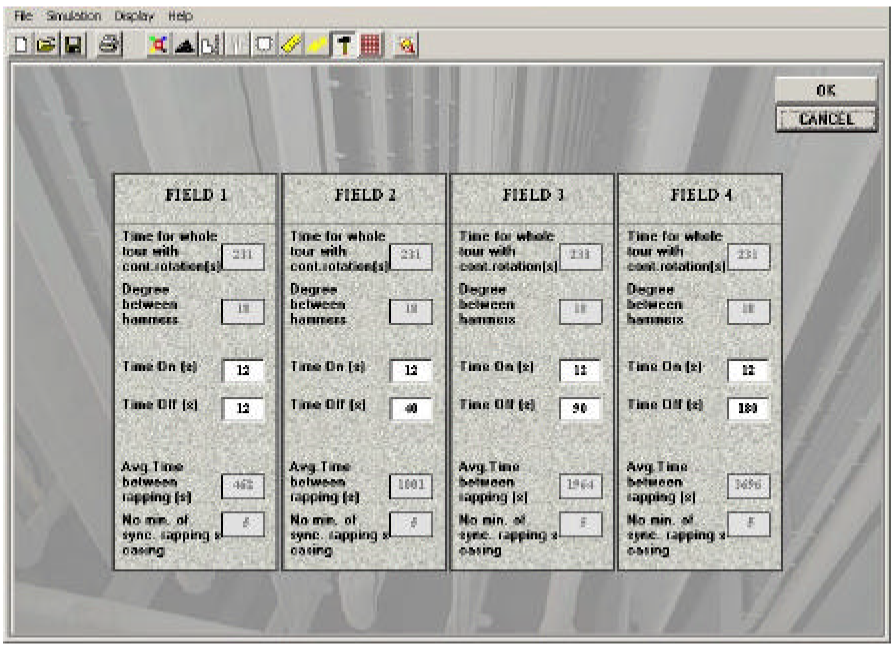

Figure 3 : screen of the rapping module

The results, in terms of thickness of the layer, is also presented field by field for each electrical power supply in a different screen (Figure 4).

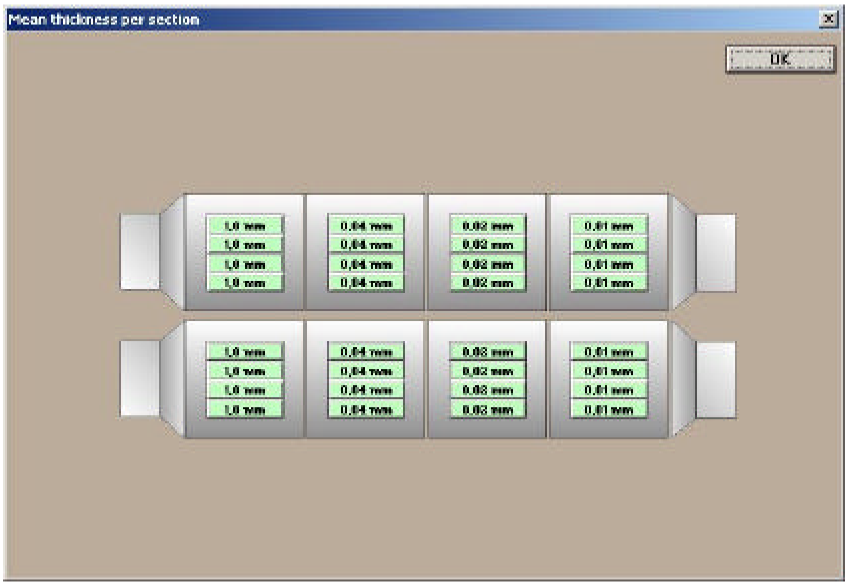

Figure 4 : screen of thickness layer

The values of input data and thickness are reported in table 1 :

Field	1 (t_p = 12 s)	2 (t_p = 40 s)	3 (t_p = 90 s)	4 (t_p = 180 s)
Thickness	1,0 mm	0,04 mm	0,02 mm	0,01 mm

Table 1 : Input data and thickness of layer

3.3. Comparison with industrial data

The effect of the variations of the rapping sequences has been tested on the electrofilter installed at Cottam Power plant on Unit 1. With respect to the usual rapping sequence, the rapping motor pause times have been multiplied by 2 (slow rapping) or divided (fast rapping) by 2.

The observed emission values for usual rapping rate were 27 mg/Nm^3 (on dry at 6% O_2) compared with 25 obtained by the ORCHIDEE simulations. Both, faster and slower rapping caused an increase in the emission level (***Figure 5***).

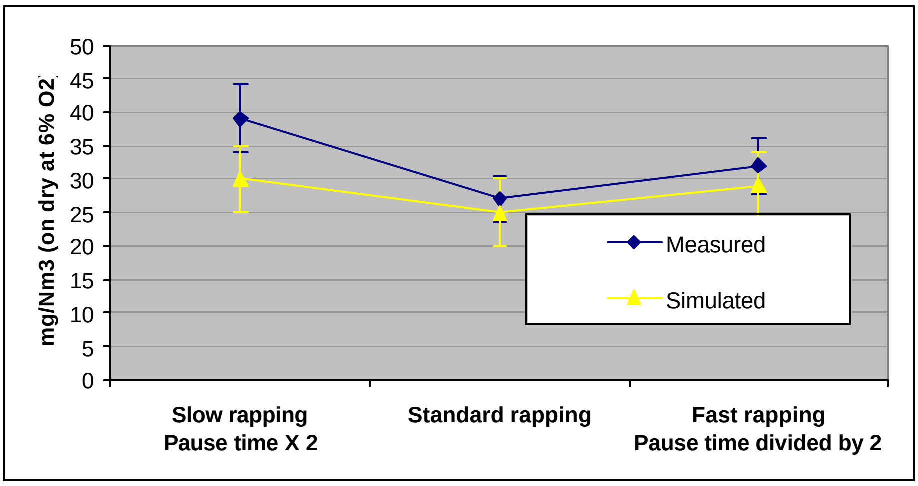

Figure 5: Experimental and simulated dust emissions at Cottam Unit 1 electrofilter as functions of the rapping frequency

CONCLUSION

The simulation of the particles trajectories performed in the ABRICOS project led to a better understanding of the layer evolution on the collecting plates. The electrostatic pressure and a viscous force could simplify the force balance approach and allow to define a simplified model estimating the sliding velocity in general terms. The experimental study of the mass balance in an industrial esp pilot provided precious data and helped with the development of a reliable model.

The model of rapping plates has been developed and integrated in the new version of the EDF-IRS software ORCHIDEE to help the plant staff to optimise their rapping sequences. It has been compared with good agreement with an industrial esp in a 500MW power plant.

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