Use of a New Prototype Electrical Aerosol Sensor to Evaluate the Collection Efficiency of a Precipitator

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Abstract - In this paper, we will present an experimental procedure to estimate the filtration efficiency of a Fil-Cylinder electrostatic precipitator. This estimate is based on the measurements of electric charge realized using a sensitive electrometer connected to an electrostatic induction probe. It is proposed to compare the experimental results for two effects: the applied potential and the mass flow rate of PVC particles of different sizes. From the results obtained, it has been found that the concentration of the particles significantly modifies the rate of variation of the recorded charge. This modification is due to the presence in suspension of the PVC particles in the inter-electrode interval. For this purpose, an electrostatic aerosol sensor (EAS) has been designed whose purpose is to be used as a means of particle detection and evaluation of the performance of the ESP.

Keywords –Electrostatic filter, electrostatic induction, electrostatic sensor, filtration efficiency.

I. INTRODUCTION

Electrostatic precipitation is a process commonly used to eliminate solid polluting particles (such as dust and ashes) or liquids (oil mist for example) contained in gases rejected into the atmosphere [1.3]. Due to the low electrical power consumption and their high filtration efficiency (up to 99.9%), the electrostatic precipitators equip with the thermal power stations or the cement plants, the machinery rooms in the wood industry or in metallurgy, offices and residential buildings, hospital, etc [4]. Nevertheless, the operation of these filters is not always stable, fluctuations in filtration efficiency occur frequently, which requires the installation of a monitoring system and reliable measurements in continuous operation [5.6]. In order to answer this requirement, the optical sensors are used, namely the radiation counters and the opacimeters [7.8]. In general, dust or smoke particle counters have a higher sensitivity than other detection systems and provide more or less significant information pertaining to the filtration efficiency. An optical counter provides the number and the size distribution of particles in real time by measuring the intensity of the emitted light [9.14]. However, the measurement accuracy is related to the relative position of the laser beam and of the air stream [15].

The major drawback of such an optical meter is that the particle concentration is underestimated. This underestimation can be attributed to particle alignment; thus, the particles are not detected by the laser beam. Moreover, on the basis of the application and the location of the measuring instrument, the sensitivity of the sensor should vary when the particles density varies from very low (high efficiency) to very high concentration (bad efficiency) [16.17]. In this work, our attention was focused on the effect of the presence of the particles which are in suspension in the filter.

The main objective of this article is to propose a novel technique for monitoring an ESP by a measurement of the electric charge dissipated through the collecting electrode towards the ground. The particularity of this technique is that it uses an electrostatic induction probe (EIP) located upstream of an electrometer in order to protect the latter against sparks [18]. With a new system for detecting fine particles using an electrostatic aerosol sensor (EAS) placed downstream of the electrostatic precipitator, which enables monitoring and calculation of performance.

II. MATERIAL AND METHODS

The installation used for the experiments of filtering and to measurement of the electric charge, can be divided into three distinct functional entities (Figure 1): the part of admission of the powder, the filtering device and instrumentation of measurement.

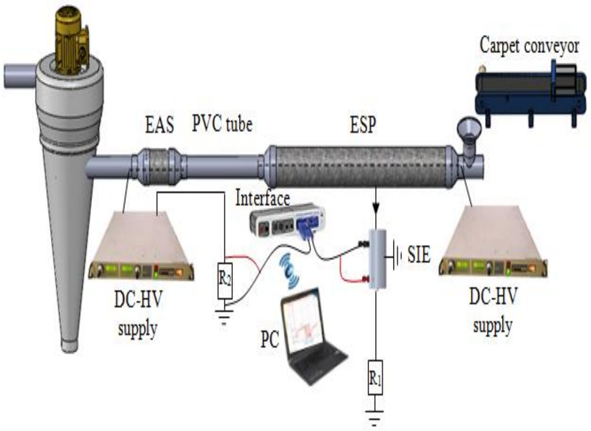

Fig. 1. Descriptive schematic of the experimental setup.

The filtering device is an ESP classic of the type "wire-cylinder" in horizontal position, comprising a galvanized tube of length 900 mm and with a diameter 110 mm. The wire corona with diameter 0.25 mm is connected to a high voltage supply. An auxiliary sensor of diameter lower than that of the ESP and a 140 mm length were added downstream from ESP. The applied voltage of the ESP (V_{ESP}) and the sensor (V_C) was provided by two negative DC-HV power supplies (V_{max} = 40 kV, I_{max} = 7.5 mA, Spellman SL 300). Powder supply of the ESP east ensured by a carpet conveyor which makes introduce the PVC particles of average diameter 63µm resulting from the operation of crushing of plastic waste. The flow velocity of the product inside the ESP was controlled by a cyclonic dust collector (Q_{max} = 150 m^3 / h) placed downstream from the filtering device which recovers the powder not filtered in order to evaluate the output of filtration by using the following classical equation:

$$\eta_1(\%) = [1 - \frac{m_{out}}{m_{Int}}] \times 100 \tag{1}$$

Where:
m_{out}: outgoing mass of the ESP (not filters)
m_{int}: total mass introduced by aspiration.

A) Electrostatic aerosol sensor (EAS)

The AES is a particle detector consisting of a "Wire-Cylinder" geometry detection cell made up of an aluminum tube (ground electrode) 80 mm in diameter and 140 mm long and a stainless steel wire (active electrode) placed in the axis of the cylindrical tube with a diameter of 0.25 mm and a length of 140 mm. The latter must be connected to the high voltage direct current generator. The ground electrode is connected to the input of the electrometer to measure the total electric charge caused by the presence of particles, neutral or charged, which are suspended in the electric field inside the detection cell, using the data acquisition interface connected to a computer (Fig. 2).

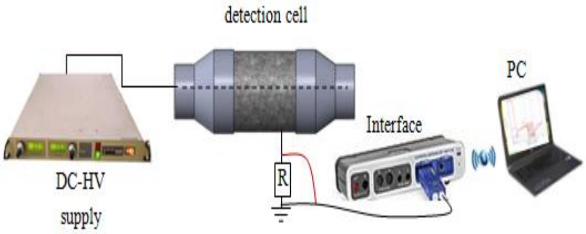

Fig. 2. Descriptive schematic of the electrostatic aerosol sensor EAS.

B) Protocol of manipulation

In order to experimentally test the reliability of our measurement technique of the filtration outcome η, the same handling protocol was adopted for all the tests (Figure 3). Before the introduction of the PVC particles, the reactor or the electrostatic sensor is put under high voltage hang a length Δt_1, during this time, the generator high voltage of the ESP is a stopped. Just after, powder is injected for a period Δt_2 and then ridge. The source of the ESP still remains at a standstill. Just after, powder is injected for a period Δt_2 and then ridge. The source of ESP always stays in the stopping. After that, the filter is turned on and the powder is again injected for the same duration Δt_2 equal to 10s. During all this time, the charge sensor continuously takes the load variation as a function of time for different situations. The following relationship is proposed for the filter performance evaluation, it is given by:

$$\eta_2(\%) = [1 - \frac{\Delta Q_{ON}}{\Delta Q_{OFF}}] \times 100 \tag{2}$$

Where:
ΔQ_{off}: is the charge difference recorded from the electrostatic sensor when the ESP generator is in the OFF position.
ΔQ_{ON}: is the charge difference recorded from the electrostatic sensor when the ESP generator is in the ON position.

The charge difference ΔQ is evaluated whether at the level of the ESP or the electrostatic collector by the following relation:

$$\Delta Q\ (\mathrm{nC}) = Q_f - Q_i \qquad (3)$$

With:
Q_f and Q_i: final charge (after filtration) and initial charge.

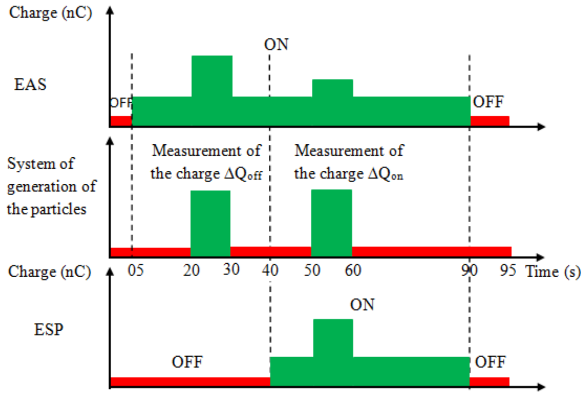

Fig. 3. Illustrative diagrams of the protocol of manipulation.

III. RESULTS AND DISCUSSION

A) Monitoring of the ESP by measure of electrical charge

The measurement system consisted in plotting the variation of the electric charge according to the protocol already illustrated in figure 3 for different values of the applied voltage V (kV) at the terminal of the ESP and the suction flow rate Q (m^3/h). The choice of the value of the high voltage of the electrostatic sensor is an influential parameter in order to avoid, on the one hand, a possible collection of dust which risks to distort the results, and on the other hand not to affect its sensitivity vis-à-vis fine particles escaping from the ESP.

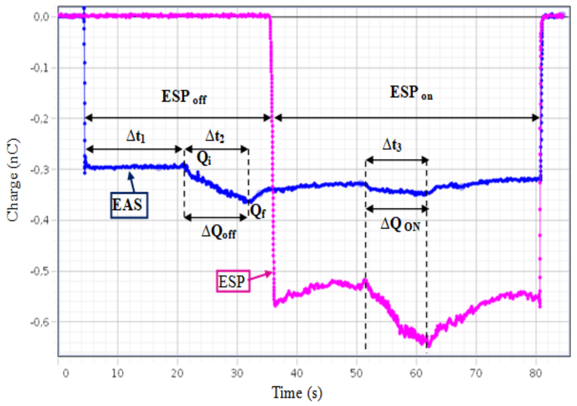

Fig. 4. Typical diagram representing the evolution of the electric charge (V_{ESP} =16 kV, Q =54 m^3/h).

Before injection of the powder, the diagram of Fig. 4 displays a constant plateau during Δt_1, corresponding to an induced charge Q_i by the ion current generated by the corona discharge of the electrostatic sensor. This plateau remains almost constant as the particles are not yet introduced by the feeding device.

However, once the particles introduced into the sensor, the pace of the plotted diagram changes instantaneously showing an almost linear and constant increase of the negative electrical charge up to a peak value Q_f, corresponding to an additional charge induced by the flow of the PVC particles (Time interval Δt_2).

Once all the particles are out of the sensor corresponding to a flow of clean air, the curve rises to reach its initial plateau indicating a decrease of the charge. During the two durations of time (Δt_1 and Δt_2), the high voltage generator of the ESP is always in the OFF position. The objective of this first charge sampling time is to define the behavior of the sensor vis-à-vis the total mass of powder since the voltage of the ESP is null (no filtration).

The second stage of charge picking is done by starting the ESP generator. For a voltage of 16 kV the ESP manages to capture a fraction of the total mass introduced, which results in a decrease in the increase in load recorded from the sensor during the time interval Δt_3, compared to interval Δt_2.

B) Evaluation of the filtration outcome η by the technique of difference of charge ΔQ

In this part, a simple and effective technique has been successfully tested in order to control online the operation of our ESP, we will calculate the filtration outcome η using the equation (3) and it will be compared in continuation with the yield obtained by the classical relation (1).

Figure 5 represent the charge variation curve for a voltage V_{ESP} = 16 kV. The voltage applied to the sensor will be fixed (V_{EAS} = 13kV) for all the rest of the experiments, because it allows us to have a good ESP monitoring without particle collection (at the sensor). The charge difference at the sensor is 0.022 nC, it pass to zero for V_{ESP} = 24 kV (Fig. 6).

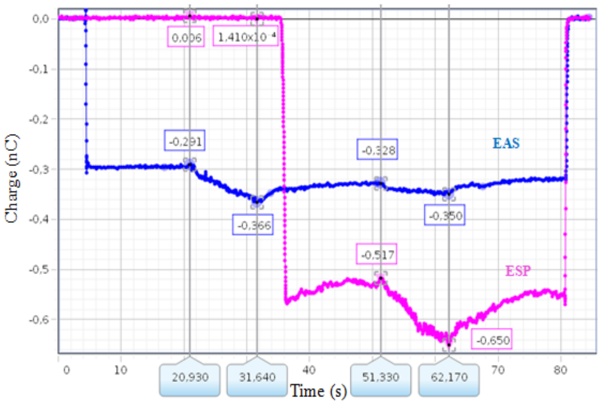

Fig.5. Variation of the charge as function of the time (V_{ESP}= 16kV, V_{EAS}=13kV).

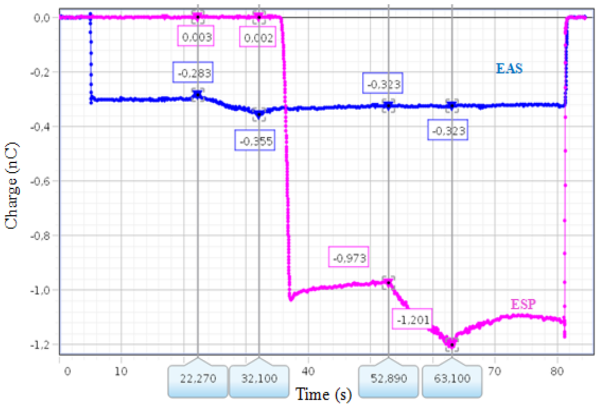

Fig. 6. Variation of the charge as function of the time (V_{ESP}= 24kV, V_{EAS}=13kV).

Figure 7 illustrates the values of the charge differences (ΔQ ± 0.005) nC at the ESP at level of the sensor in state off and one of ESP for different voltages by the applied filter. It is clear that the more VESP increases, the difference ΔQ decreases, which is due to the decrease of the unfiltered outgoing mass.

The filtration outcome of our filter was calculated by the relation 3 in order to make a comparison with that obtained by the relation 1. Figure 8 clearly shows the variation of the η as a function of V_{ESP} for a mass flow rate of 1g/s using the two calculation methods. The results obtained show an almost perfect agreement of the measurement of the yield between the two methods. An analogy between the two curves makes it possible to identify the value of the constant k that exists between the two measurement techniques.

We can bestowal establish a relation between the two returns, it is given by :

$$\eta(\%) = \eta_1(\%) = k \times \eta_2(\%) \tag{4}$$

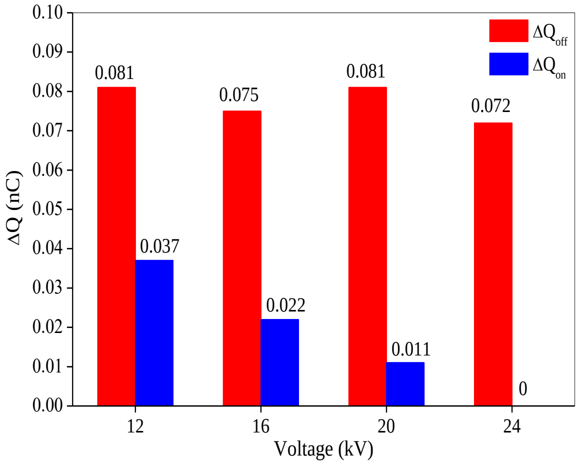

Fig. 7. Histogram of the variation of the ΔQ_{ON} as function of the V_{ESP} for a mass throughput of 1g/s.

For our case, the constant K is equal to 1.1. It should be noted that the difference between the two performance measurement techniques strongly depends on the sensitivities of the scale used and the charge cell.

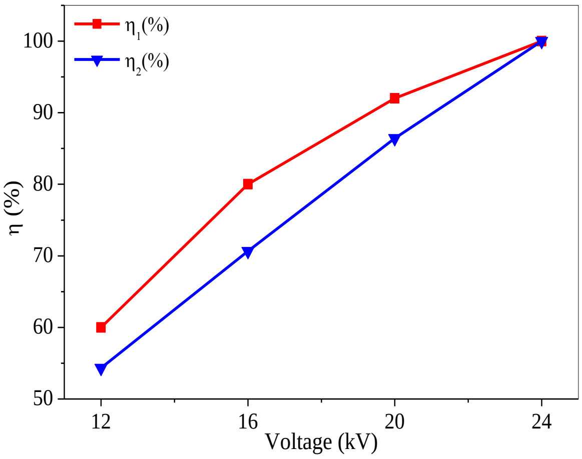

Fig. 8. Comparative curves of the calculation the filtration outcome as function of the V_{ESP}.

C) Monitoring of the ESP as a function of the duration of operation

The monitoring of industrial precipitators must be ensured in real time in order to act in the event of a problem of operation. In order to test the reliability of our filter operation monitoring technique, we set a voltage V_{ESP} = 24 kV, which corresponds to a 100% efficiency and we calculated the variation of the filtration outcome by the two measurement techniques on an interval of time varying from 10s to 25s.

Normally, the η must be degraded as a function of time. From figure 9, it is clear that both variations have the same pace, which means that our technique is reliable and can be used for ESP monitoring.

Figure 10 illustrates the response of our electrostatic sensor in case of degradation of the yield of the filter. The unfiltered mass which increases as a function of the operating time results in the increase of ΔQ_{on}.

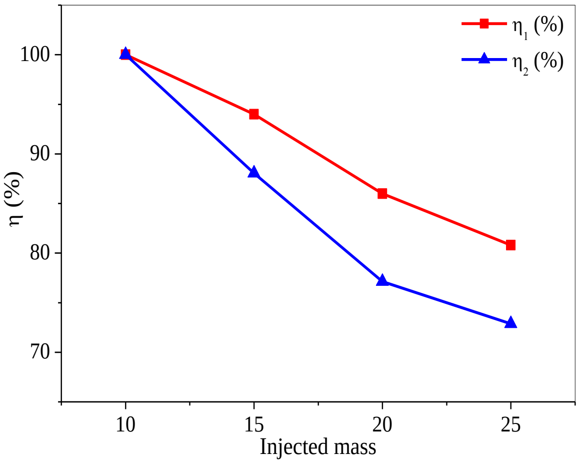

Fig. 9. Variation of efficiency as a function to the duration of operation (V_{ESP}= 24kV, V_{EAS}=13kV, 1g/s).

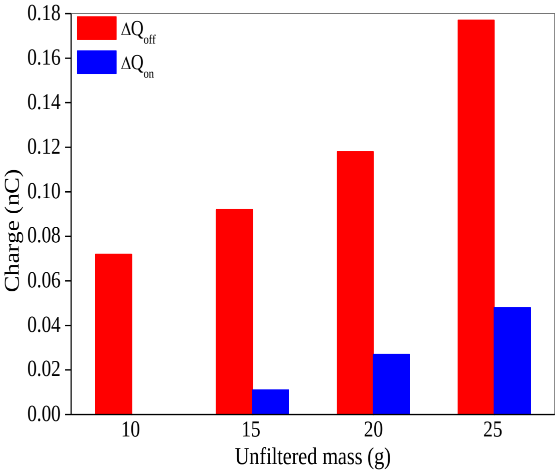

Fig. 10. Answers of the electrostatics sensor following the degradation the filtration outcome of ESP (V_{ESP}= 24kV, V_{EAS}=13kV, 1g/s).

D) Monitoring de l'ESP en fonction du débit massique

Our sensor is also sensitive to possible fluctuations in mass flow. Indeed, any change in flow rate of the pollutant is instantly indicated by the change in the shape of the charge curve, as shown in figure 11, obtained for V_{ESP} = 24 kV and a flow of suction ai Q = 54 m3 / h. This figure was plotted by varying the material flow rate suddenly from 30 g / min to 120 g / min. It is clear that the response and sensitivity of the sensor is instantaneous for both states of the high voltage source of the ESP (ON and OFF). The increase in mass flow significantly affects the filtration efficiency.

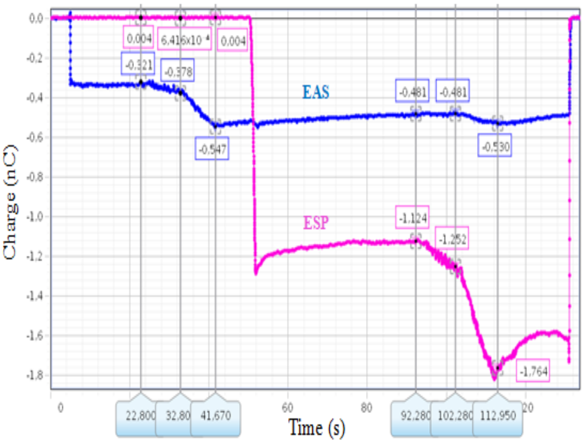

Fig. 11. Variation of the charge for two different values of the mass flow (0.5g/s and 2g/s).

IV. CONCLUSION

An experimental study was conducted in this paper to validate a new technique for measuring the performance of an ESP. This technique is based on the measurement of the electrical charge caused by the presence in suspension of the particles in the inter-electrode space. Indeed, this has been justified by the various curves obtained, which show that the charge difference recorded from the electrostatic aerosol sensor (EAS) is mainly due to the interaction between the concentration of the particles with the electric field. The results obtained have shown that this new method gives precise measurement values and allows a good monitoring of an electrostatic process such as the filtration of dust or fumes. In addition, the use of a new electrostatic induction probe (EIP) enabled us to perform ESP charge measurements with a sensitive electrometer without risk of deterioration.

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