Optimization of a Cost-Effective "Wire-Plate" Type ESP for Installation in a Medical Wastes Incinerator

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***Abstract* -- Although research on electrostatic precipitators (ESPs) have studied and analyzed all the technical aspects of this device, their cost is nowadays the major constraint for manufacturers and users. Therefore, medical waste incinerators of hospitals in Algeria, as well as municipal waste incinerators, operate in most cases without flue gas filtration system due to the high costs that requires the installation of a cleaning system. This constraint is reflected in the Maghreb and African countries. The objective of this paper is to show that it is possible to build-up a cost-efficient electrostatic precipitator, including a high voltage power supply made-up of a static converter and a step-up ferrite transformer. A home-made "wire-plate"-type half-scale prototype ESP was carried out and used to optimize the filtration efficiency according to the inter-electrode distance and to determine the optimum voltage to be applied without risk of breakdown.**

***Index Terms*— electrostatic precipitator, high voltage power supply, incinerator**

I. INTRODUCTION

Electrostatic precipitators (ESPs) have been known for over a century and are widely used for air cleaning [1-8]. Besides the huge electrostatic ESPs that purify the flue gases of cement plants, foundries or thermal power stations, many smaller-size units have been developed for the treatment of ambient air in workshops, offices, hospitals. In addition, ESPs are especially applied to municipal and medical wastes incinerators [9-11]. The electrostatic precipitator is very popular for this purpose, because the smoke particles generated from waste combustion are in the submicron range with variable concentration. The most effective collection device technology is generally an ESP based on DC corona discharge. Particle collection by this technique is advantageous because of high collection efficiency especially (up to 99.9 %), low pressure drop, and very small energy consumption [12-14].

In most countries of North Africa and even Africa, hospitals are equipped with medical waste incinerators. However in most cases the filtration system is defective or just nonexistent. Indeed, the filtration system represents a significant investment and the budget of these hospitals is not sufficient to order the installation of a cleaning system which is expensive [15]. The incinerator of university hospital center (CHU) of Sidi-Bel-Abbes, in Algeria, does not have a filtration system; it operates during several hours daily, emitting harmful fumes inside the CHU and around it.

Collection efficiency of the device may not be extremely high but should be sufficient to significantly reduce the emission of the combustion into atmosphere. Collection efficiency of the designed ESP will be studied and geometrical parameters will be varied to obtain the highest efficiency possible.

The aim of this paper is to show that it is possible to build-up a cost-efficient "wire-plate" ESP type for the incinerator powered with a high voltage power supply consisting of an electronic inverter, a ferrite step-up transformer and a diode bridge to obtain DC voltage. A half-scale model was carried out, which was used for an experimental study by considering the most significant factors: inter-electrodes distance and the applied voltage.

Thereafter, a full scale model will be produced and installed for the incinerator based on the optimal values obtained from this study. A full-scale model to be installed at the exit of the incinerator is being manufactured, on the basis of optimal values obtained from this study. The electrostatic precipitator will be powered by a DC high voltage power supply consisting of a control circuit comprising an NE555 timer, a power circuit of two MOSFETs, a step-up ferrite transformer and a diode bridge for rectifying.

II. EXPERIMENTAL DEVICE AND METHOD

We have opted for the "wire-plate" ESP type because it can treat higher gas flow rate than the cylindrical model. A half-scale model was carried out, which makes it possible to vary two important geometrical parameters which are the distance between electrodes and the number of corona wires.

As shown in Fig. 1, the ESP comprises plate electrodes of

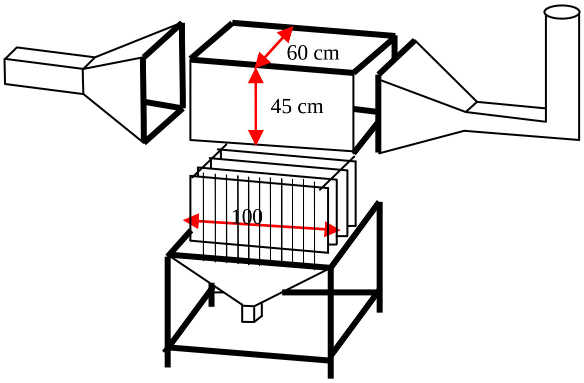

Fig. 1. The electrostatic precipitator

dimensions 100 x 45 cm^2 whose number varies depending on the value of the inter-electrode distance. The ionizing electrodes are constituted by a row of 5 vertical wires of 0.1 mm diameter (Fig. 2). The plates are connected to the frame of the ESP, this latter being grounded, while the wires which are connected to DC high voltage are isolated from the carcass using Teflon insulators.

Smoke is produced within a container generated by burning rubber chips; a fume extractor fan is located downstream at the outlet of the ESP, having adjustable flow rate with maximum value of 1200 m^3/h.

The applied voltage was delivered by a commercial high voltage power supply, however, given its high cost, a home-made HV power supply is under construction. It is made using a static converter, a step-up ferrite core transformer and a rectifying diode bridge.

Fig. 3 shows the block diagram of the high voltage power supply under construction. The power supply consists of a control circuit block, which aims to generate a high frequency square signal and a power block composed of two Mosfets controlled by the square signal. Input voltage is decreased to 24 V using a step-down transformer 220/24 V, which is rectified and then fixed at a constant value of 15 V using a voltage regulator LM7815.

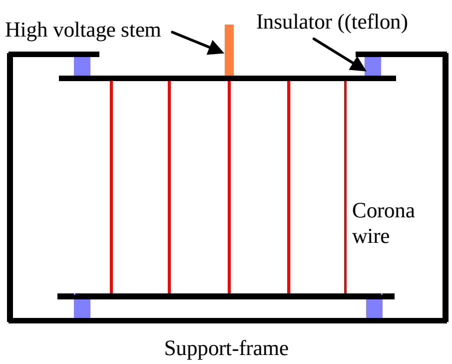

Fig. 2. Ionizing electrode of the ESP

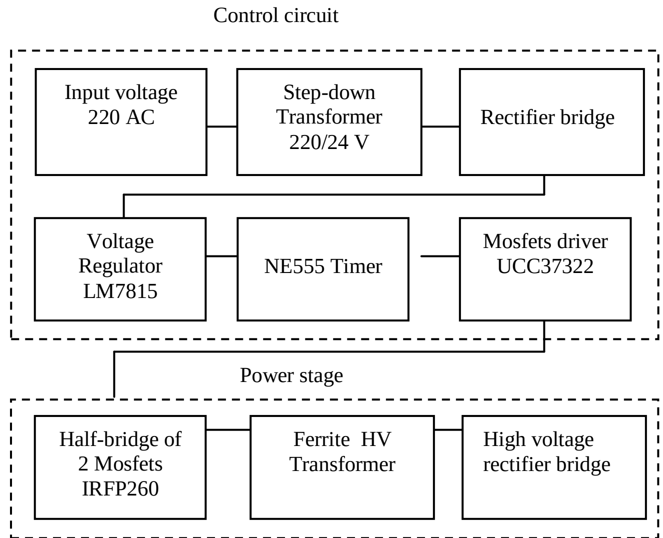

Fig. 3. Block diagram of the high voltage supply

This voltage (15V DC), used to power a NE555 timer circuit, is transformed into a square signal of adjustable frequency ranging between 10 and 100 kHz using a potentiometer. The square signal coming out of the timer is then amplified using a driver of Mosfets UCC37322. At the same time, a rectified and adjustable voltage (0-310 V), that feeds the primary of a step-up ferrite transformer of power 1000 W, is transformed in a high frequency signal by the Mosfets (IRF640) controlled by the timer square signal, thereby obtaining an adjustable high voltage output.

The AC voltage is then rectified using a diode bridge. This power supply is not expensive because a ferrite-core step-up transformer is employed, which is much smaller and cheaper than conventional transformer (Fig. 4). The cost of this supply will not exceed 500 USD.

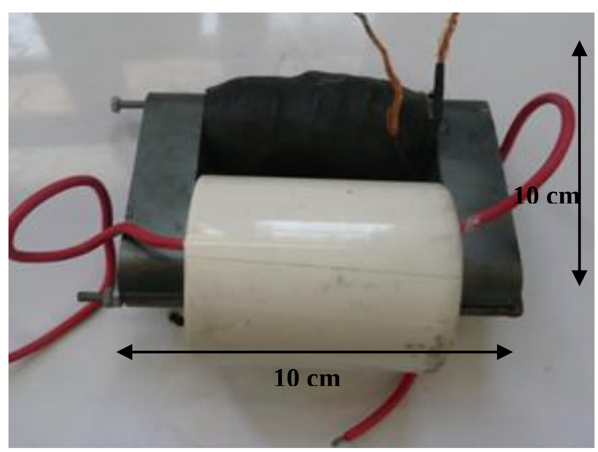

Fig. 4. HV ferrite transformer

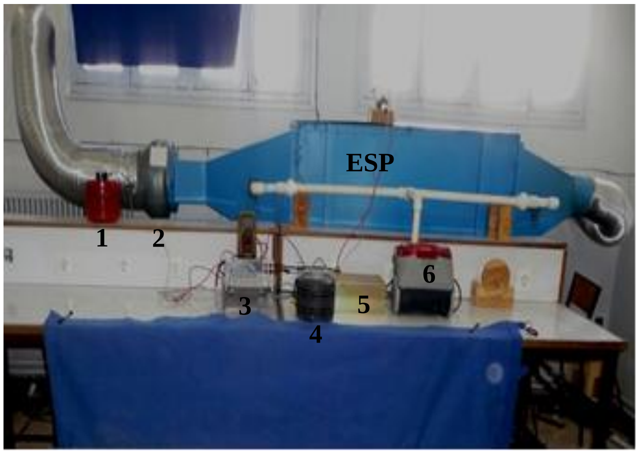

Fig. 5. Experimental setup. 1- Variac for flow control of the fan; 2 - fan; 3-Multimeters; 4-Variac to control the high voltage; 5-high voltage power supply; 6-vacuum cleaner

Electrical measurements of the electrostatic precipitator were performed with the experimental device of Fig. 5.

The current-voltage characteristic (or I(V) curves) of the ESP was determined by measuring the current produced by corona discharge as function of the applied voltage, until breakdown. The current was measured using a digital multimeter (Keithley 2000) placed in series to ground and the voltage was measured with a probe voltage of ratio 1:100 (Metrix HT212).

Collection efficiency measurement was conducted using the experimental setup of Fig. 5 according to the descriptive scheme shown in Fig. 6 [16]. A vacuum cleaner of 1200 Watt power is used to suck the flue gas upstream and downstream of the ESP, with the same flow rate adjusted to 25 L/min using a ball flowmeter, during a duration time of 10 seconds.

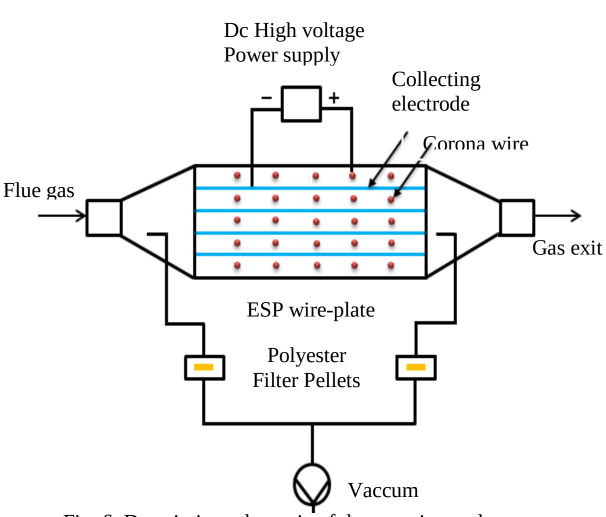

Fig. 6. Descriptive schematic of the experimental setup

Filter pellets made of Polyester (air permeability 100L/dm^2/min, thickness 1.5 mm, resistance to temperature 150 °C) were used to measure the efficiency.

These filter samples were weighed using an electronic balance of 0.1 mg precision (KERN ALJ 200 – 4NM) before and after each experiment to determine the mass of retained smoke. The collection efficiency (η) was calculated using the following formula:

$$\eta(\%) = 100 \times \left(1 - \frac{m_{out}}{m_{in}}\right) \quad (1)$$

with

m_{in}: mass of smoke collected upstream of the ESP

m_{out}: mass of smoke collected downstream of the ESP

III. Results and Discussion

A. Electrical Characteristics of the ESP

At first, the evolution of corona discharge as a function of the applied voltage (I(V) characteristics) was determined.

Since the width of the precipitator remains unchanged, equal to 60 cm, each value of the inter-electrode interval *d* (*d* = 6 cm, *d* = 7.5 cm, *d* = 10 cm) corresponds to a different number *n* of ionizing electrodes (*n* = 5, *n* = 4, *n* = 3).

The current-voltage characteristics obtained for the three configurations with positive polarity are shown in Fig. 7. The total current increases with the applied voltage if it exceeds a certain threshold value, until breakdown of the gaseous medium.

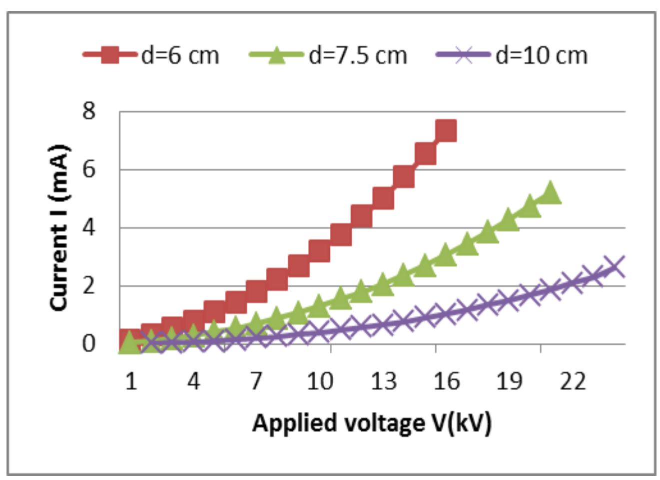

Fig. 7. Characteristic I(V) of the ESP

The current flowing through their inter-electrode space is a nonlinear function of the applied voltage. For a constant voltage, the discharge current of configuration *d* = 6 cm is much higher, this is related to the intensification of the average electric field and the large number of active electrodes.

However, it is in this configuration that the breakdown voltage of the gas is the lowest, posing significant risks to the reliability of power supply. The variation of the average power as a function of the applied voltage is shown in Fig. 8 for three configurations. At fixed voltage, the results showed again a high power consumption of the configuration *d* = 6 cm.

B. Collection efficiency of the ESP

The experimental study of the collection efficiency was performed by varying the applied voltage for three values of the inter-electrode distance (*d* = 6, 7.5 or 10 cm). The polyester filter samples removed upstream and downstream of the ESP are shown in Fig. 9 for the case of *d* = 6 cm.

As expected, the color of the filter sample, used to collect the smoke particles, changes depending on their location (upstream or downstream) and the level of the applied voltage. Upstream, filter samples recover a large amount of particles, which significantly changes their color.

Downstream of the ESP, the amount of collected particles is becoming smaller with increasing voltage. The photographs of the collecting electrodes before and after a long period of gas treatment confirm also the qualitative efficiency of the ESP (Fig. 10).

As shown in (Fig. 11) , the collection efficiency increases with the applied voltage in the three configurations.

This is explained by the enhancement of the particle charging and drift process when the electric field is increased. That is the configuration *d* = 7.5 cm which offers the best collection efficiency at constant voltage (up to 90% in the available voltage range).

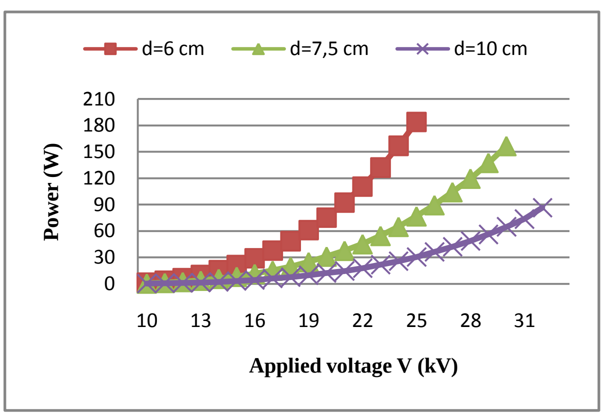

Fig. 8. Variation of the power consumption of the ESP as a function of the applied voltage

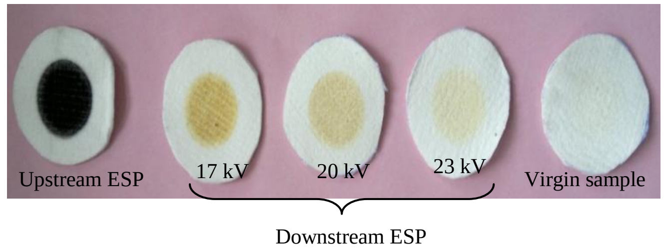

Fig. 9. Photographs of the filter samples

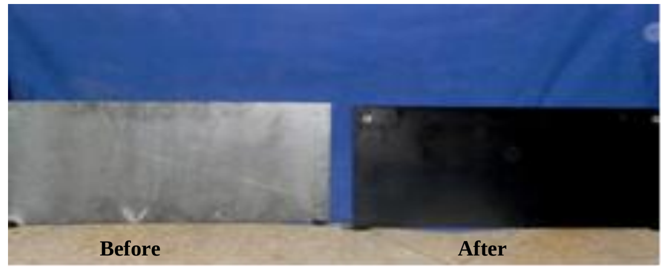

Fig. 10. Photographs of the collecting electrodes before and after gas treatment

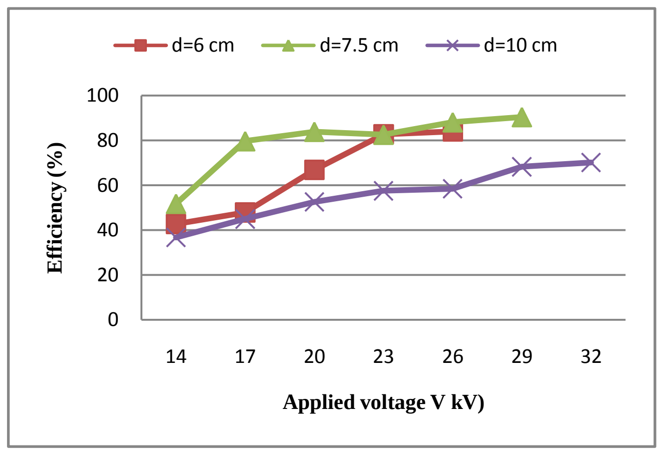

Fig. 11. Variation of the efficiency according the applied voltage

The collection efficiency increases gradually with the power consumption (Fig. 12). The configuration d = 7.5 cm nevertheless has a definite advantage because it has a lower energy cost for superior performance: 80% of the particles are collected for a power less than 20W.

The ESP to be installed at the exit of the medical wastes incinerator is under construction (Fig. 13), its installation will be carried out according to the assembly shown in Fig. 14.

A turbine is used to suck the smoke from the incinerator and to convey it and pass through the ESP. The turbine must be adjusted at a defined rate to suck the flue gas and mainly

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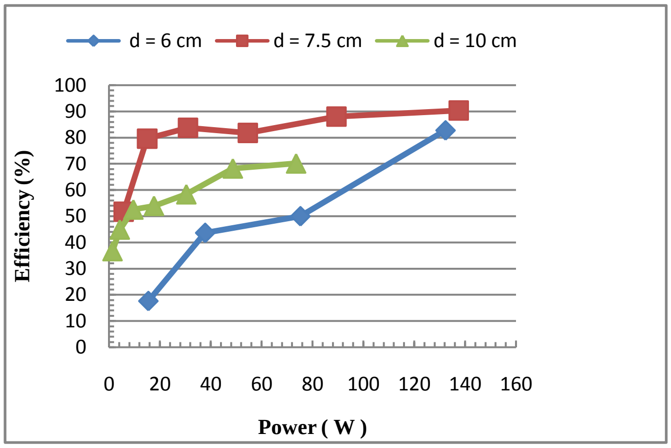

Fig. 12. Variation of the efficiency according to consumed power

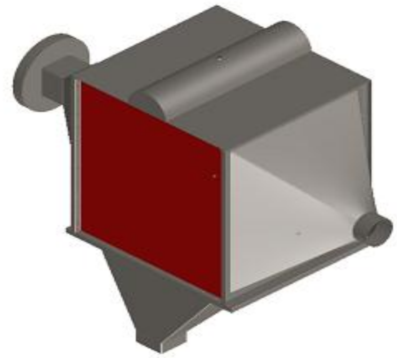

Fig. 13. Overview of the ESP under construction

A turbine is used to suck the smoke from the incinerator and to convey it and pass through the ESP. The turbine must be adjusted at a defined rate to suck the flue gas and mainly avoid «aspiration of fire flames", the setting being provided by a variable speed drive. The removal of the flue gas layer collected on the electrodes will be done by cleaning with water jet.

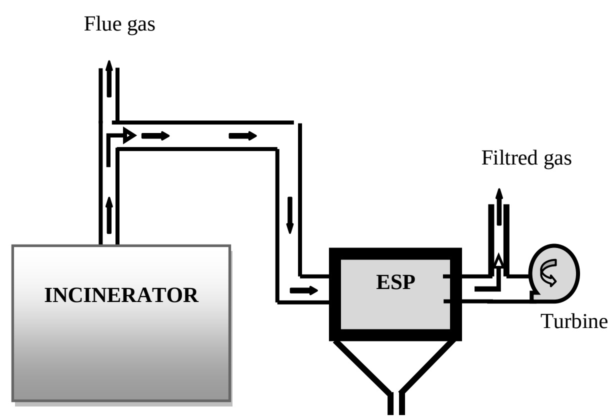

Fig. 14. Filtration system to be installed for the hospital wastes incinerator

IV. Conclusion

The medical waste incinerators in hospital centers in Algeria particularly and in Africa in general work in most cases without filtration gases fumes. We have shown in this paper that these incinerators can be equipped with cost efficient "wire-to-plate" type electrostatic precipitators. These ESPs will be fed by static converters and high voltage ferrite transformer. A half-scale electrostatic precipitator was built and tested in the laboratory. The filtration efficiency of the device is still not very high but should be sufficient to significantly reduce emissions from combustion into the atmosphere.

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