REMOVAL OF FINE AND ULTRAFINE COMBUSTION DERIVED PARTICLES IN A WET ELECTROSTATIC SCRUBBER

L. D'Addio, F. Di Natale, C. Carotenuto, G. Scoppa, V. Dessy, A. Lancia
francesco.dinatale@unina.it
Dipartimento di Ingegneria Chimica, dei Materiali e della Produzione Industriale
Università degli Studi di Napoli "Federico II"
P.le V. Tecchio, 80 80125 Napoli

Abstract
This paper presents experimental results on the particle capture efficiency achieved in a wet electrostatic scrubber, equipped with a specially designed corona source and induction spray nozzle to generate a stream of charged particles and a spray of droplets with opposite polarities. This unit was specifically designed and constructed for marine diesel engine emission control within the activities of the 7EFP project DEECON – Innovative Technologies for Marine Diesel Engine Emission Control. Experiments were carried out on a model combustion gases with fine and ultrafine particles ranging from 10 to 1000 nm, and revealed that total particle capture efficiency as high as 93% can be easily achieved. This result, coupled with the well-known properties of water scrubbers as acid-gas absorber, suggest that the wet electrostatic scrubber is a reliable and very promising technique for exhaust gas cleaning with application for both industry and transport sector.

Introduction
The wet electrostatic scrubber (WES) is a technique to remove submicron particles from exhaust gases that can integrate or even substitute conventional fabric filters and electrostatic precipitators to upgrade fine and ultrafine particles removal efficiency in gas cleaning systems. In its main mechanical constituents, a wet electrostatic scrubber is a modification of conventional spray towers, with a dedicated electrified spray system and, optionally, a particle charging unit that produce streams of charged droplets and particles. In this sense, the WES inherits all the structural and process advantages of scrubbers, such as the low pressure drops and the simple design and operation, as well as the ability to simultaneously remove soluble gases and particulate matter. If compared with fabric filters and electrostatic precipitators, the WES presents lower power consumptions and footprints and may achieve particle removal efficiencies comparable or even higher than the other conventional or innovative gas cleaning systems [1-4].
In spite of its potentialities, WES unit are rarely produced at industrial scale. In

part, this scarce diffusion is related to the absence of specific regulations on the abatement of submicron particles for industrial activities, but it also derives from the limited number of scientific and technologic experiences with this process. Moreover, these experiences were largely carried out on micrometric size particles, for which only a slight improvement of particle removal efficiency respect to conventional scrubbers was found. However, few tests were performed on fine or ultrafine particles, and they showed a dramatic increase in the removal efficiency [1-3, 5-7] which strongly support the interest in verifying the reliability of the WES process for the removal of this fraction of particulate matter in exhaust gases.

This paper presents experimental results on the particle capture efficiency achieved in a wet electrostatic scrubber. This unit was specifically designed and constructed for marine diesel engine emission control within the activities of the 7EFP project DEECON – Innovative Technologies for Marine Diesel Engine Emission Control. This unit includes specially designed corona source and induction spray nozzle to generate a spray of droplets and a stream of charged particles with opposite polarities.

Tests were carried out on a model combustion gas at atmospheric pressure and temperature, treated in a WES column with a spray of tap water. Experiments were carried out in three different conditions: i) uncharged spray and particles; ii) uncharged particles and charged spray; iii) spray and particles charged with opposite polarity.

Materials and Methods

Wet electrostatic scrubbing tests were carried out in a pre-pilot scale system sized to treat 200 Nm^3/h of gas. The WES chamber was a stainless steel column 400 mm ID and 3500 mm height equipped with a pneumatic spray nozzle electrified by induction (EFS) and with a particle charging unit (PCU) that made use of a corona source to ionize the gas and charge the particles with polarity opposite of that of the sprayed droplets. The gas and the spray streams flowed co-currently in the scrubber.

The source of particles was a free flame of gasoline generated with a naphtha lamp. The flue gas were aspired by an exhaust fan and contained around 10^{12} particles/m^3 having size ranging between 10-1000 nm and with average diameter around 180 nm. Tests were carried out by spraying tap water with an operating liquid-to-gas mass ratio of 1.16 kg/kg. Two levels of charging potentials, 0 and 15 kV were used for the electrified spray nozzle. The same values were used for the particle charging unit.

The analysis of particulate matter was carried out with a TSI 3910 and a TSI 3340 devices operated in parallel. The analytic system included a pretreatment section composed by thermodenuder, a 1:1000 dilutor and a particle neutralizer. The TSI 3910 allows measuring particles in the range 10-420 nm, while the TSI 3340 covers a particle size range between 90 and 7500 nm. The two devices were used to determine particle concentration and particle size distribution (PSD) in a fixed sampling point of the experimental set up, place at the exit of the WES chamber, before the exhaust fan. These data were eventually used for the determination of particle removal efficiency in each particle size. The instrumentations also provided the total, numerical, particle concentration, from which an overall particle removal efficiency can be derived.

Results and Discussion

Fig. 1 describes the particle size distribution generated by the gasoline flame.
The figure shows that the particulate matter is bimodal

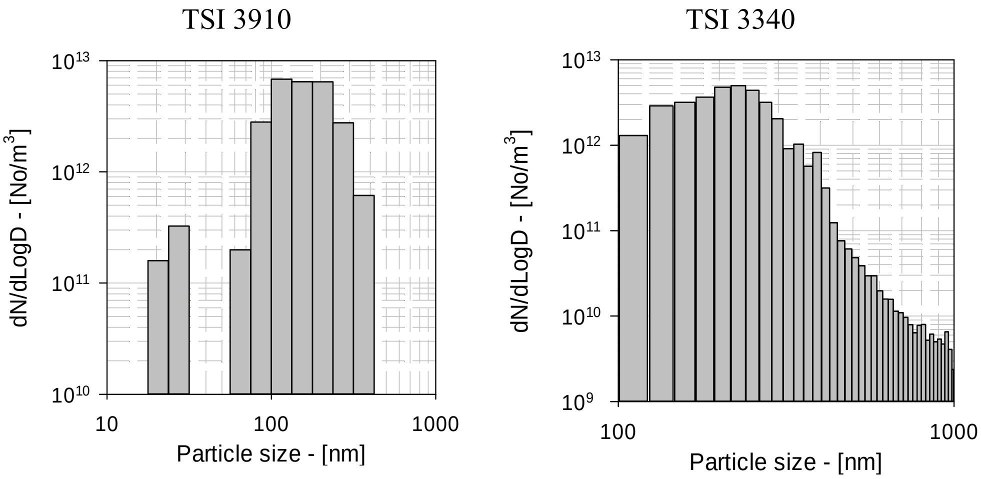

Figure 1. Particle size distribution generated by the gasoline flame.

In the different tests, particle concentration is almost constant and close to 10^{12} #/m^3. The average particle diameter is about 190 nm.
When the WES chamber is operated with an uncharged spray and particles, the particle removal efficiency η was very limited, being above 10% for particles finer than 220 nm, but resulted almost null for coarser particles (Fig. 2). The corresponding value of the overall particle removal efficiency is around 5%.
The scrubbing efficiency increased when particle size decreased from 200 to 60 nm due to Brownian diffusion capture mechanisms. However, the values of particle abatement efficiency at 20 and 30 nm did not follow this trend.
No appreciable variation of the average particle diameter was observed in this experimental conditions.
When only the spray is charged, with an induction potential of 15 kV, the particle abatement efficiency strongly increased reaching an overall value of about 35%. The experimental results are shown in Fig.3.

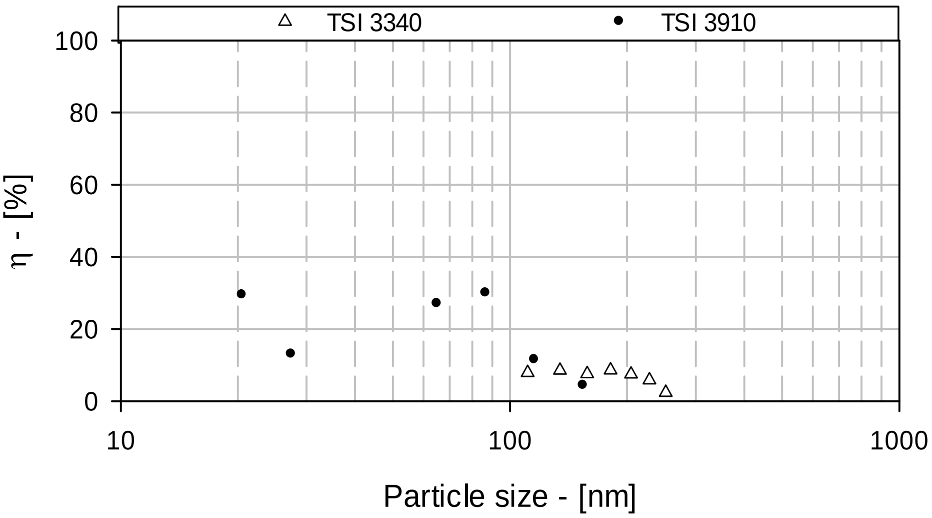

Figure 2. Particle removal efficiency for the WES operated with uncharged spray and particles.

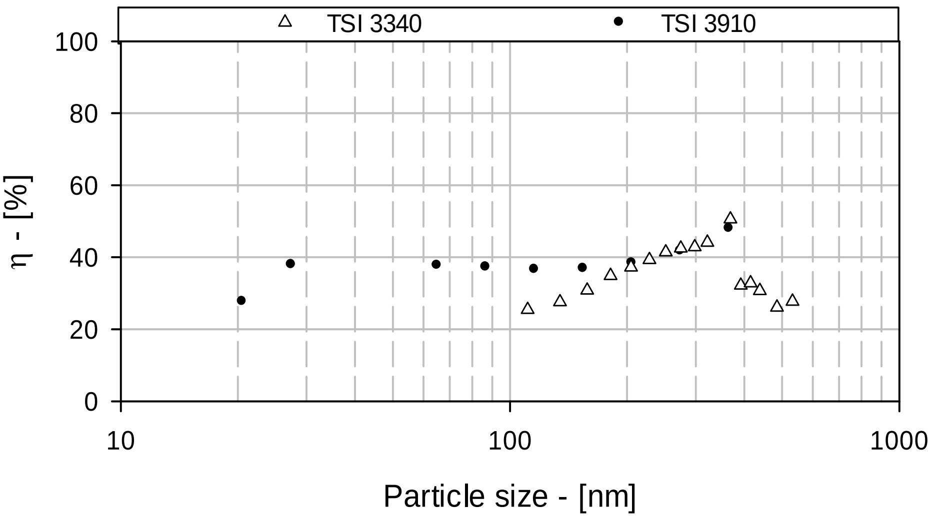

Figure 3. Particle removal efficiency for the WES operated with charged spray (EFS at 15 kV) and uncharged particles.

In this case, the particle abatement efficiency increased for all the particle size respect to the conditions of Fig.2, but especially in the range 200-1000 nm it present the most dramatic change, passing from almost 0 to 30-50%. Indeed, this

higher abatement efficiency is determined by the onset of image charge forces between charged droplets and uncharged particles. Since the particle capture efficiency is almost uniform over the entire range of size distribution, the average particle diameter remains slightly unchanged and close to about 190 nm as the original PSD in absence of scrubbing.
Finally, when both the spray and the particles are both charged with opposite polarities, the particle abatement efficiency presented a dramatic increase, as shown in Fig. 4.

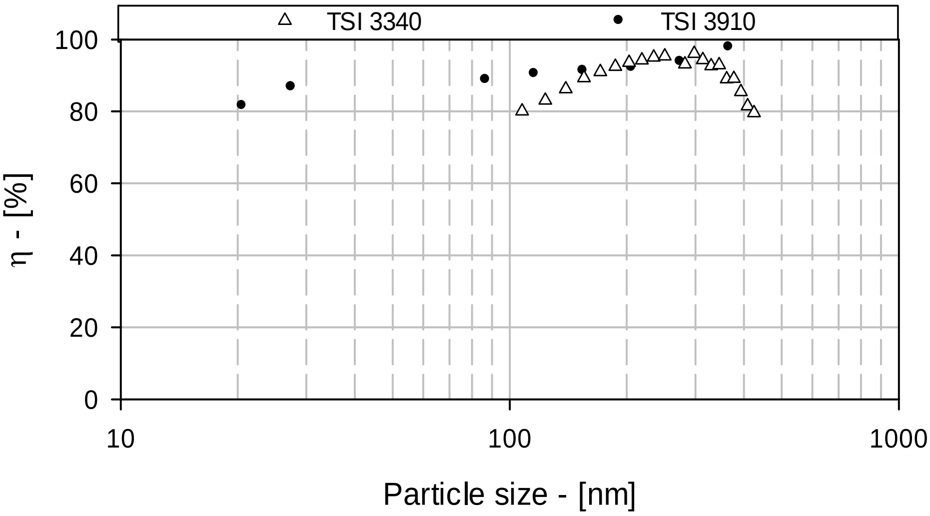

Figure 4. Particle removal efficiency for the WES operated with charged spray (EFS at 15 kV) and charged particles (PCU at 15 kV).

In this case, particle abatement efficiency was very high, reaching values close to 95% for particles of 300 nm and resulting higher than 80% for particles in the range between 20 and 1000 nm. The overall abatement efficiency was about 93% and the particle diameter reduced to about 160 nm.
The higher abatement efficiency is related to the occurrence of Coulomb interaction between droplets and particles charged with opposite polarities.

Conclusions
This paper describe the results on wet electrostatic scrubbing of fine and ultrafine particles by means of an electrified spray of tap water produced by a pneumatic – induction charging nozzle and of a corona source unit used to pre-charge particles.
Tests were carried out on a model combustion gas at atmospheric pressure and temperature, which contains around 10^{12} particles/m^3 having size ranging between 10-1000 nm and with average diameter around 190 nm. Tests were carried out by spraying tap water with an operating liquid-to-gas mass ratio of 1.16 kg/kg.

When the system was operated with uncharged droplets and particles, the numerical particle size distributions showed an overall particle removal efficiency of about 5%, with a maximum level, around 25%, achieved for 10% particles finer than 100 nm due to Brownian diffusion scavenging mechanism. When the water spray was charged (15 kV charging potential), the particle capture efficiency reached an average value of about 35% and presented a non-monotonic trend: efficiencies of about 40% were observed for particles of about 40 nm and 400 nm. Finally, when both the particles and the spray were charged (-15kV and +15kV respectively), the particle capture efficiency dramatically increased, reaching a total value of 93% with a maximum close to 95% for 300 nm particles.
The comparison of the experimental results confirmed that electrostatic interactions are far more effective then hydrodynamic interactions and they actually determine the higher abatement efficiency of the WES system. Needless to say, more intense Coulomb forces led to higher abatement efficiency respect to image charge forces that arisen when only droplets were charged and the particles were polarized. These experimental results demonstrated that the wet electrostatic scrubbing can be considered as a viable and very promising technology to remove fine and ultrafine particles from combustion off-gases, having performances comparable or even superior than those achievable with conventional technologies adopted in this field.

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