# Wet electrostatic scrubber (WES) development for the abatement of submicronic particles

## A new modern electro-filter technology jointly developed in recent years to fight PM emissions

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Increasingly frequent alarms due to the outbreak of threshold limits for fine particles in the atmosphere have been recorded in recent years. Particulate matters (PM) consist of solid or liquid particles suspended in the air having many shapes, sizes and chemical composition (10 nm – 100 μm). The largest of these can also be seen with the naked eye, whereas others can only be seen through powerful microscopes. These suspended particles come from different sources such as natural phenomena or anthropic processes as combustion processes, industrial emissions, household activities, etc.

Generally, particulate matters are classified according to their size: coarse or $PM_{10}$ (2.5-10 μm), fine or $PM_{2.5}$ (<2.5 μm), submicronic ($PM_1$) and ultrafine (UFP, <0.2 μm). Usually, $PM_{10}$ and $PM_{2.5}$ are used to define air quality, but recent studies have revealed the high toxicity of submicronic powders, suggesting the need to consider them as responsible for a significant risk to exposed people. Toxicological studies have long understood how toxicity depends on the surface area and the size of the particles, rather than their mass. Ultrafine particles can cross cellular membranes reaching blood circulation and giving rise to severe damages to many organs **(Figure 1)**

This recognised toxicity is the reason why the most advanced regulations on particulate control, i.e. those in force for motor vehicles, limit both the mass and number of particles emitted, as it was considered the best way to hold emissions within acceptable toxicity limits.

Current regulations for stationary combustion sources, as power plants and industrial activities, and air quality standards exclusively refer to the mass of $PM_{2.5}$ and $PM_{10}$, despite the danger of the finest particulate matters. Although the restriction of the particulate mass concentration is not enough to limit the toxicity significantly, the governmental entities comprehend the existence of a technological limitation in capturing a high number of submicronic particles with existing commercial solutions, especially if the economical competitiveness of industrial applications has to be preserved.

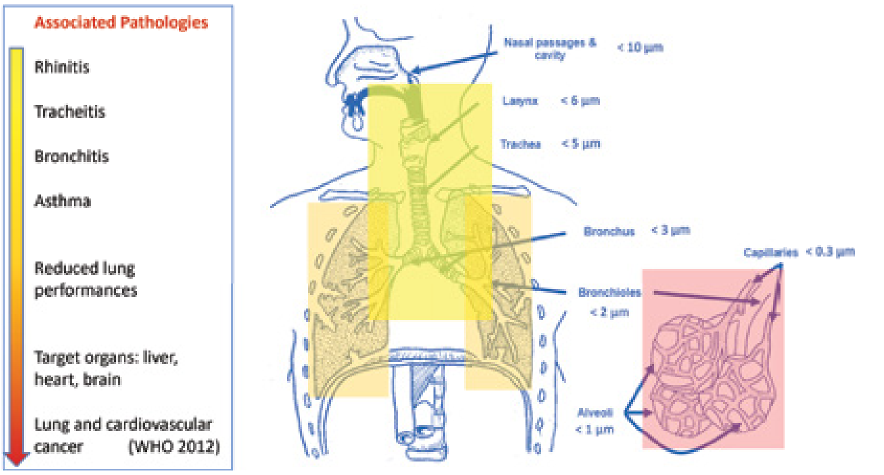


*Figure 1 - Diseases correlated to the level of particles penetration into the respiratory system.*

## Electrostatic precipitators and Wet Scrubbers for PM removal

Two of the most consolidated technologies for particulate abatement in the industrial field are electrostatic precipitators and wet scrubbers.

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Electrostatic precipitators (ESPs) have been widely used since the middle of the 20th century. In the ESP, the dust suspended in the gas is electrically charged as the effect of a high-intensity electric field. The charged particles deviate towards the collection electrodes, as the effect of the electric field. The greater the surface charge induced on the particles, the greater the electric force that moves the particle towards the collector, hence increasing the probability of capture. Oils, particles with electrical resistivities and densities outside of the optimal range, as well as particles finer than 500 nm are hard to capture in an ESP.
Spray towers, or "Wet Scrubbers" (WS) represent the most versatile strategy for the combined abatement of particulates, oils and acids. The particle capture, in WS, is based on the hydrodynamic interception of particles against the droplets, which allow high particle abatement efficiency for particles having enough inertia, like those in the micrometric range or for nanometric particles subjected to an appreciable Brownian motion. Particles that impact the liquid droplets, coming from the sprays, are most likely trapped in the liquid phase, hence cleaning the gas. The most important parameters for WS design are the drops size and velocity and their volumetric density, which determines the probability that particles in the gas come into contact with the droplets. As a consequence, the design of the contact chamber and the spray properties are thus critical parameters for WS design.
The capture efficiency decreases significantly for submicronic and ultrafine particles, for both electrostatic precipitators (ESP) and wet scrubbers (WS). A new wet electro-filter technology called "WES" has been developed in recent years and it is being tested on a pilot scale for the abatement of submicronic particles.

## WES as a combination of ESP and WS

Since 2013, the Environmental Division of Boldrocchi S.r.l. is performing intensive research and development activities to develop innovative and high-effective technologies for the removal of submicronic and ultrafine dust. The company is developing a Wet Electrostatic Scrubber (WES) in partnership with the University of Naples Federico II.
The WES synergically uses the main points of strength of ESP and WS, i.e. the effective use of the electric field to move particles regardless of their low inertia and the availability of a distributed collector that is unaffected by the physical nature of the particles. In a WES unit, the gas enters first a section called Particle Charging Unit (PCU), where it is exposed to an optimised corona discharge at medium electric potential (15-20 kV). Low current intensity micro-discharges, of the order of nano or microamperes, increase the surface charge of the particles that are passing through the PCU. The particles charging is optimised to achieve the desired particles charging in a compact unit, with a residence time that is 4-5 times smaller than the ESP.
The charged particles leaving the PCU enters a contact chamber, where they meet charged droplets that are generated by electrified sprays (Droplets Charging Unit, DCU). Further to the directional interception and the inertial impact, another phenomenon contributes to the capture of the particles in the WES: if particles and droplets have opposite charges, they are electrically

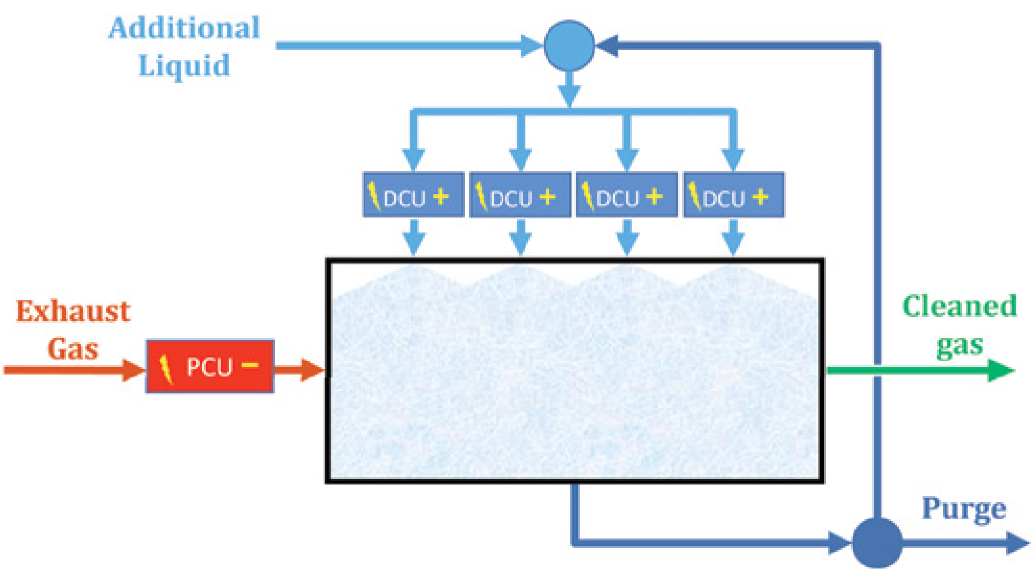



*Figure 2 - Block Diagram of a closed-loop configuration of a horizontal cross-flow closed-loop WES unit*

attracted to each other by improving the dust removal. The block diagram of a closed-loop WES configuration is shown in **Figure 2** where a partial (>95%) recirculation of the liquid is included and additional water and purge streams are included to preserve system functioning and optimise particles capture performance.

**Figure 2** refers to the horizontal crossflow unit, that is currently adopted by Boldrocchi, but the WES can be designed using other configurations to optimise space occupancy and system performances for different industrial conditions.

The electrified spray (ES) allows the generation of droplets having a defined surface electric charge. The droplets charge also take place at medium electric potential with extremely low energy consumptions. The charged droplets offer the double advantage of giving rise to the electrostatic interactions that increase the trapping of particles and of enhancing the dispersion of droplets in the contact chamber. In the WES, particle penetration decreases up to 20 times compared to conventional WS operated at the same liquid-to-gas ratio[1,2], and at least halves that of a conventional ESP. Further studies have also shown that the absorption rate of acid gases is 15% faster for WES compared to WS thanks to the electrostatic interactions between charged droplets and acids molecules[2,3,4].

In 2016, Boldrocchi company, together with the University Federico II built the first WES on a pilot-scale for the gas treatment (up to 10,000 Nm³/h) from industrial processes (e.g. incinerators, cement factories, steel mills, etc.). Similarly to **Figure 2**, the plant was a horizontal cross-flow unit, which operated with a liquid/gas ratio between 1 and 2 kg/kg.

In a first configuration, the WES was intensively tested from 2017 to 2019 in the Company's test room, using a model gas consisting of air enriched with test dust made of an inert mixture of sand and salt. The dust distribution was in the desired submicronic range (90-500 nm with a median of about 150 nm), and the electrosprays were fed with tap water. More than 70% of the dust finer than 200 nm was removed, while the percentage increased up to 98% for larger particles, at the fixed L/G ratio of about 1.5 kg/kg. The electrical consumption of the loading units of the WES was approximately 20 mWh/Nm³, against the 500 mWh/Nm³ typically observed for ESP, with a pressure drop measured on the chamber of less than 0.7 mbar (**Table 1**).

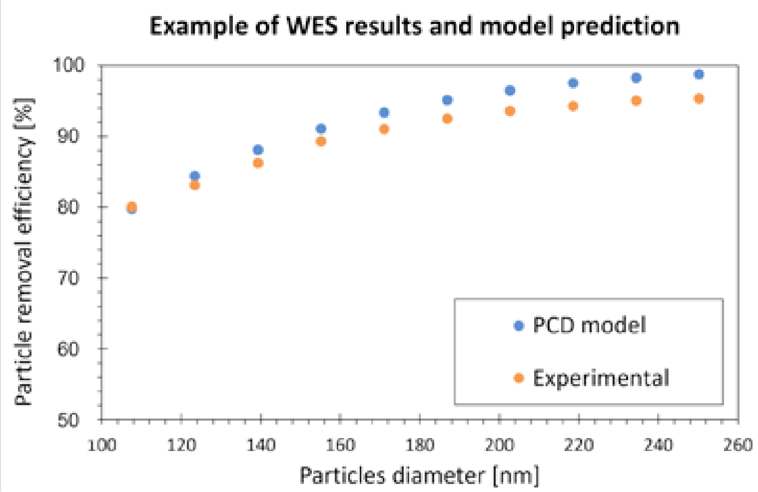



*Figure 3 - An example of a comparison between the experimental and model prediction of the particle removal efficiency in the WES process.*

*Figure 4 - WES installation in a Waste to Energy (WTE) plant*

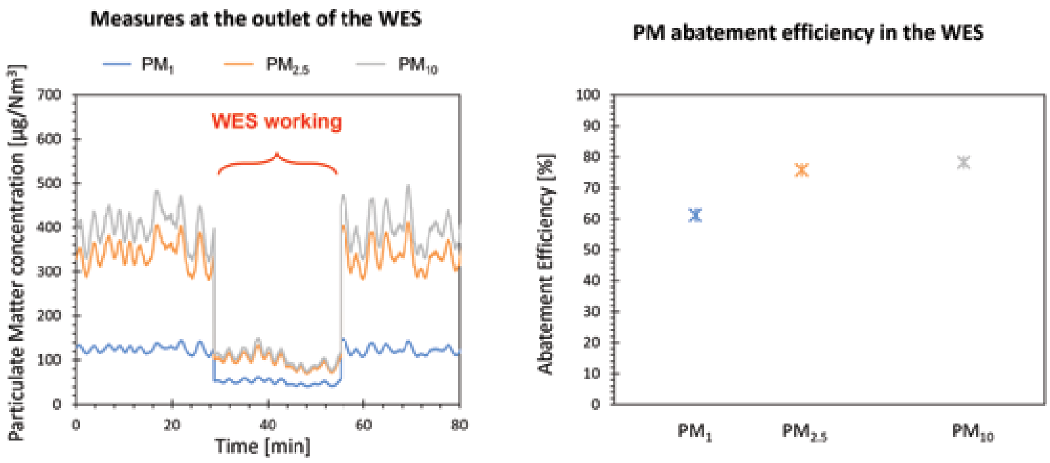
This setup was thoroughly analysed and a dedicated proprietary physico-mathematical model was developed to support the design and optimization of industrial WES units. The model approximated the results from experimental tests with an accuracy above 90%, as is shown in **Figure 3**.

In 2021, the Company installed the pilot-scale WES in a recirculation line of a waste-to-energy (WTE) plant in Italy (**Figure 4)**. The exhaust gas cleaning train of the plant used a fabric filter unit for PM removal that guaranteed the emission of the particles always below

| Gas Flow rate | L/G ratio (Liquid/gas) | Particle size | Efficiency | Electrical consumption | Pressure drop |
|---|---|---|---|---|---|
| 5500 Nm³/h | 1.5 kg/kg | < 200 nm | > 70% | 20 mWh/Nm³ | 0.7 mbar |
| | | > 200 nm | < 98% | | |

*Table 1 - WES performances on model gas*

*Figure 5 - Performances on WTE flue gas after the fabric filter: reduction of the PM concentration (left) and abatement efficiency (right)*




2 mg/Nm³. The recirculation was introduced after the fabric filter unit and reinject the gas before the fabric filter, to allow compliance of the emissions and preserve the representativeness of the emission control system placed before the plant stack. The WES was installed as a retrofit for the abatement of the submicronic particles that were around 2-5·10⁵ #/cm³, consistently with the low particulate emissions at the chimney of incinerators equipped with a similar exhaust gas cleaning train. The treated gas stream was 4500 Nm³/h and the liquid-to-gas ratio was slightly below 1 kg/kg.

Despite the very low particles concentration and the very low liquid-to-gas ratio, which reduce the removal efficiency, the WES unit allowed reducing the emissions by more than 80%, for $PM_{10}$, 75% for $PM_{2.5}$, and 60% for $PM_1$, with a reduction of particles number above 70% for particles finer than 50 nm (**Figure 5**).

Due to the low concentration of pollutants (PM and acids) at the WES inlet, the system operated in a closed-loop mode, with a total water consumption below 0.02 kg per kg of treated gas. Besides, the maximum power consumption for the loading WES units was 25 mWh/Nm³ and the pressure drop was of 0.5 mbar.

Tests will be performed in the next months to further explore the performances of the WES unit for this application, thanks to better integration with the existing fabric filter unit aimed to optimise the particle capture.

## Conclusions

WES will find application in many industrial sectors, where low concentrations of submicronic and ultrafine particles are required. Low energy consumption and low-pressure drops allow an easy integration within existing gas cleaning trains either for newbuilds and retrofit conditions. Furthermore, the high capacity of particles and acids removal at low temperatures makes the WES system particularly suitable as a revamping of low-efficiency wet scrubbers for the removal of fine, submicronic and ultrafine particles.

After the successful completion of the pilot-scale tests, Boldrocchi company will be ready to commercialize the WES technology for industrial application in 2022, with extension to other sectors in the following years. In particular, Boldrocchi is part of a joint venture with other companies for the building, installation and experimentation of a pilot-scale WES unit for marine diesel engine exhaust gas treatment, that will be put in operation in the first half of 2022.

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### (Endnotes)

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3 *Di Natale F., Carotenuto C., Caserta S., Troiano M., Manna L., Lancia A., Experimental evidences on the chemi-electro-hydrodynamic absorption of sulphur dioxide in electrified water sprays, Chem. Eng. Res. Des. 146 (2019) 249–262. doi:10.1016/j.cherd.2019.04.006.*

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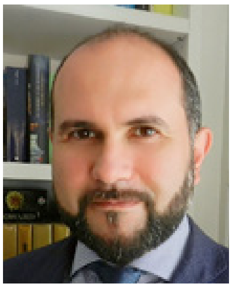
## Luigi Amato

Luigi Amato is a chemical engineer with 4 years of experience in chemical and electrical processes for pollution control. He is a R&D engineer in Boldrocchi Group where he is working on the research and industrialization of innovative and low-cost technologies (e.g. WES and non-thermal plasma) for the abatement of pollutants (particulate matters, acids, NOx). Luigi got a master's in chemical engineering in 2017 and he obtained the PhD in 2021. He is leading projects in the sector of air pollution control with other companies and university partners (i.e. University of Naples Federico II and the Brunel University of London).

## Matteo Giavazzi

Matteo Giavazzi is responsible of operations and technology development in Air Pollution Control Division of Boldrocchi Group. He started his career in automotive industry with FCA environmental research team; afterwards he focused professional activity in manufacturing industry. Over the last 20 years, he has held varying roles in environmental process engineering for industrial plants and project management. He is a specialist in environmental problems analysis, with particular reference to air pollution from industrial sources. Giavazzi has a Master's degree in Environmental Engineering from the University of Pavia, Italy; he collaborates with Chemical Engineering Department of Naples University "Federico II".



## Francesco Di Natale

Francesco Di Natale is a Chemical Engineer and a Professor of Unit Operations and Sustainable Process Design at the University of Naples Federico II. He has more than 20 years of experience in the development of sustainable technologies for pollution control and recovery of added-value chemicals (precious metals, combustion nanoparticles…) from waste streams. He is specialized in the design of multiphase-flows (absorbers, adsorbers, fabric filters, fluidized bed units) and electrical-driven (chemi-electrohydrodynamics and cold plasma technologies) processes. His typical field of application is in the treatment of gas and water streams produced by industrial and civil processes and by internal combustion engines, as well in the filtration of bioaerosols.