Multiyear monitoring of ultrafine particulate matter emissions from a modern full scale WtE plant at real operating conditions.

Cernuschi S.[1*], Lonati G.[1], Puricelli S.[1], Tardivo R.[1], Ozgen S.[2], Signorini S.[2]

[1]Dept. of Civil and Environmental Eng. (DICA) - Env. Sect., Politecnico di Milano, P.za L. da Vinci 32, 20133 Milano (Italy)

[2]LEAP (Lab. for Energy and Environment Piacenza), Via N. Bixio 27/c, 29121 Piacenza (Italy)

*corresponding author. E-mail: stefano.cernuschi@polimi.it

Abstract. Monitoring campaigns for addressing quantitative and qualitative characteristics of emitted ultrafine and nanoparticles during real operating conditions from waste to energy were performed on a modern plant with a specifically designed instrumental protocol. Results are summarized for number concentrations and size distributions of particles during sampling conditions representative of both primary particles at stack flue gas and of those arising from dilution and cooling techniques, for identification of variations theoretically expected immediately following immissions in the receiving atmosphere.

Keywords: Emissions, ultrafine particles, field measurements, waste to energy plant.

1. Introduction

Particulate matter produced from waste combustion for energy conversion (WtE) is one of the most important pollutants in plants flue gas emissions for health-related and, more generally, for all additional implications on broad environmental burdens of the source category. Most recent scientific acquisitions (Jones and Harrison, 2016) had shown increasing significance for smaller size fractions, included in the ultrafine and nanoparticle size ranges (≤ 100 nm and ≤ 50 nm, respectively), particularly related to their ability to reach deeper respiratory airways and to be potentially translocated to other systems, thus increasing awareness for human toxicity. This has led to a general enlargement of their attention in regulatory and technical concerns, establishing their inclusion in actual and prospective strategic planning and control frameworks (EU, 2024) and the need for an extension of monitoring exercises able to estimate their gas presence (RI-URBANS, 2024). Dedicated protocols have been consequently established for determining the presence of the size fractions of interest and their distributions, normally needed to be evaluated in terms of particle numbers instead of conventional mass determinations, due to their very low dimensions (RI-URBANS, 2024). Monitoring might be properly capable of further addressing the effects of cooling flue gas by the receiving atmosphere of stack emissions, potentially driving gaseous condensation and particle nucleation effects that affect general aerosols concentration and size.

The text outlines main results of measuring campaigns conducted at stack of a modern WtE in full operating regimes. Data acquired include investigations both addressed to primary particles as they are in the gas and those arising from flue gas cooling and dilution effects (condensation sampling), all conducted with the same specifically designed instrumental protocol for stationary source and ambient air measurements. Results are examined and analysed comparatively, also with data obtained for the same plant in identical sampling protocols during previous different yearly periods, and a general comparison is reported with air levels measured simultaneously in the surroundings of the plant.

2. Field investigations setup

Stack emissions were investigated at an urban waste incineration (WtE) plant, designed with two parallel grate-burning furnaces with post-combustion chamber and an energy recovery section for combined heat/electricity production. Flue gas treatment is provided by post-combustion SNCR with NH_3 injection, two dry system scrubbers (DSI) in series with bicarbonate and activated carbon addition upstream fabric filters and a final SCR $DeNO_x$ reactor. Plant nominal operating capacity design equals 130,000 t/y (nearly 8.1 t/h for each line) of urban waste residual from mechanical on-site treatment separations, with average LHV of roughly 16,000 kJ/kg. Particle measurements were performed with a two-stage heated isokinetic sampling line, previously described extensively (Ozgen et al., 2015), operated both in hot (same flue gas temperature) and in cold dilution conditions and equipped with an ELPI® impactor for number concentration and size distribution evaluations in the range between 7 nm and 10 μm aerodynamic particle diameter.

3. Results and discussion

Measurement results for hot and cold sampling conditions are reported in Table 1, in terms of average concentration and geometric mode particle size ranges detected. Hot samples, oriented at evaluating the primary presence of particles in flue gas, always result below noise level of the detection protocol instrument ($8.7\cdot10^2$ #/cm^3). During cold conditions, concentrations gave rise to measurable levels between $280\cdot10^3$ #/cm^3 and $480\cdot10^3$ #/cm^3 at low dilutions (dilution ratio < 35) and with an expected reduction to $60\cdot10^3$ #/cm^3 - $180\cdot10^3$ #/cm^3 for higher dilutions (DR > 55). Despite oscillations in short term particles of very small size normally acquired during full scale plant exercise conditions, cold test measurements confirm interventions on fines particles formation of theoretical potential effects mentioned before, with their expected progressive attenuation with higher dilution ratios, arising from partial pressure reductions of gaseous species involved in the phenomena (Schaber et al., 2002). Size distributions, not detectable in hot conditions, show during cold sampling comparable characteristics: total ultrafine (≤ 100 nm) and nanoparticle (≤ 50 nm) fractions are included in the range 94÷96% and 76%÷78%, respectively, with geometric mode values located within nanoparticulate matter (35 nm) and slightly towards coarser fractions (95 nm) with increasing dilutions. Regarding comparisons with ultrafine content and characteristics of the atmosphere of the site, the situation monitored result in any appreciable effect of primary stack emissions from the plant, with total average concentrations recorded equal to $9.1 \cdot 10^3$ #/cm^3 and size distributions located within nanoparticles (GMD = 32 nm) and with contributions of nano- and ultrafine fractions of 94% and 81%, respectively.

Table 1. Particle number concentration (TPN, 10^3 particles/cm^3) and geometric mode size (GMD, nm) detected.

Sampling	TPN	GMD
Hot conditions	n.d. (< 0.9)	n.d. (< 7)
Dilution conditions		
Low (DR* < 35)	280 - 480	35 - 42
High dilution (DR* > 45)	61 - 180	46 – 95
Atmosphere (stack height)	9.1	32

*DR = dilution ratio

The same general situation was also observed in all previous campaigns. In hot sampling conditions, stack concentrations result mostly lower than noise background levels of detection protocol (Figure 1), confirming very small values, when detectable, in the whole ensemble of monitoring exercises, that include maximum results roughly between 10^3 #/cm^3 and $1.1 \cdot 10^4$ #/cm^3 obtained during 2014-2018 yearly periods. Cold sampling measurements show greater variations, with average range of results generally shifted towards more consistent records but without appreciable trend in monitored values, which appear mostly comparable for all sampling dilution conditions applied. Results available (Figure 1) indicate average particle concentration levels in the range between $2 \cdot 10^3$ #/cm^3 - $6.7 \cdot 10^5$ #/cm^3 and $5 \cdot 10^3$ #/cm^3 - $9 \cdot 10^5$ #/cm^3, for low (DR < 30) and high (DR > 40) diluted conditions, respectively. As could be directly observed from the figure mentioned highest values, exceeding nearly $2 \cdot 10^5$ #/cm^3, result less frequent and correspond to the lower dilutions applied in sampling, whilst an order of magnitude decrease in maximum levels was recorded with more significant dilution degrees. Size distributions are generally quite repeatable, with most sampling periods and dilution situations not arising in significant shifts of the particle fraction, being largely located in the ultrafine region.

4. Concluding remarks

Despite limitations still present in available documentation for the specific sector (Buonanno and Moraska, 2016; Jones and Harrison, 2016; Kumar et al. 2013; Moreno-Rios et al, 2022; RI-URBANS, 2024) and the different approaches adopted for measurements, results obtained for WtE investigated are essentially comparable with similar installations and sampling conditions, both for hot than cold conditions. Furthermore, no measurable effects of plant stack emissions of primary origin could be appreciated with respect to the atmospheric presence of ultrafine and nanoparticles detected at the same time on the site, with even the apportioning role of particles of secondary origin from gas cooling after air dilution that seems to bear very little significance.

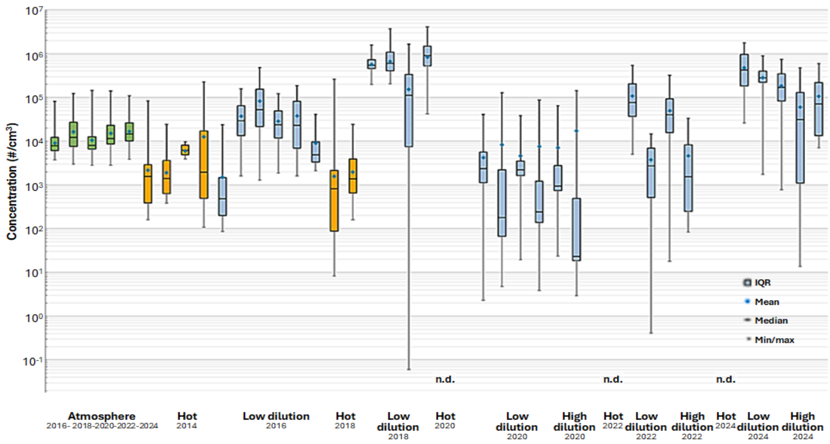

Figure 1. Particle concentrations measured in hot and dilution sampling conditions for all campaigns.

References

Buonanno G., Morawska L., 2015. Ultrafine particle emission of waste incinerators and comparison to the exposure of urban citizens, Waste Management 37, p. 75-81.

EU, 2024. Directive of Parliament on Ambient Air Quality and Cleaner Air for Europe. PE-CONS 88/1/24 REV 1, Strasbourg (France).

Jones A.M, Harrison R.M, 2016. Emission of ultrafine particles from the incineration of municipal solid waste: A review, Atmospheric Environment 140, p. 519-528.

Kumar P. Pirjola L., Ketzel M., Harrison R., 2013. Nanoparticle emissions from 11 non-vehicle exhaust sources: a review, Atmospheric Environment 67, p. 252-277.

Moreno-Ríos A., Tejeda-Benítez L., Bustillo-Lecompte C., 2002. Sources, characteristics, toxicity, and control of ultrafine particles: an overview, Geoscience Frontiers, 13, 101147, p. 1-15.

Ozgen S., Cernuschi S., Giugliano M. (2015). Factors governing particle number emissions in a waste-to-energy plant, Waste Management, vol. 39, p. 158-165.

RI-URBANS, 2024. Guidance documents on measurements and modelling of novel air quality pollutants in urban Europe: Summary and added value. EU H2020 Research Programme, https://riurbans.eu/project/#service-tools.