Wet electrostatic scrubbing for advanced dust cleaning in sinter plants

Model predictions are presented on the use of wet electrostatic scrubbing (WES) as a means of removing different kinds of submicron particles present in the exhaust gases of sinter plants. The WES system can remove over 90% of iron, silica and alkali chloride particles by using 1kg of electrified water per kg of gas. WES units provide removal of acid compounds and can overcome some of the limitations of electrostatic precipitators (ESP) and bag-filters in sinter plant applications.

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Iron and steel production is one of the major world industries. Often, industrial sites are large and close to cities, usually as a consequence of the development of urban areas close to industrial sites. In Italy, this was the case at the ILVA site in Taranto and the ex-Italsider plant in Naples. Sinter plants in the European Union produce about 130Mt/yr of sinter and, on average, gas emissions are about 1,500-2,500Nm^3/t of sinter.

Steelworks produce large amounts of dust, usually in the range 100-1,500mg/Nm^3 (all processes), and specific regulations are implemented to limit their final atmospheric emissions.

In most of the European sinter plants, gas flow rates are over $5 \cdot 10^5$ Nm^3/h, and a sequence of ESPs and bag-filters are used to reduce dust content respectively from about 1,500 to ≈50-300mg/Nm^3 in the ESP and within 1-15mg/Nm^3 in the bag filter. The particle size distribution varies from nanometers to hundreds of micrometers, but while ESP easily removes the coarse particles, the fine particles are reduced by less than 60% due to their alkali-chloride content. This leads to the need for special ESP designs or use of additional bag-filters. *Table 1* shows the typical mass composition of sinter dust, sampled from the third field of an ESP unit **[1]**.

Although the actual regulation limits are defined by mass concentrations, it is widely accepted by scientists, medics and engineers that the right metric for particle exposure risk is their number concentration and not their mass. Mass emissions emphasise the occurrence of larger particles, since mass emissions are 'weighted' according to the third power of particle diameter. However, research papers have

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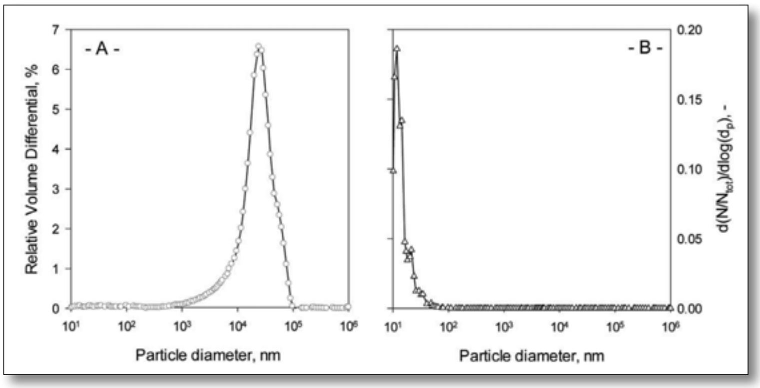

Fig 1 **Particle size distribution in terms of volume distribution (A) from [2] and corresponding extrapolation of normalised particle concentration, d(N/N$_{tot}$)/dLog(d$_p$) (B).**

Element	%w/ w	Element	%w/ w	Element	%w/ w
Fe	44-50	Ca	7.6-7.8	Pb	0.09-6.0
Cl	3-26	Al	0.4-2.2	Na (as Na_2O)	0.6-32
S	0.2-4.1	Mg	1.0	Ni	0.003
Si	2.7-3.6	Zn	0.03-0.34	Cd	0.0009
C	2.9-6.1	Mn	0.10-0.31	Ti (as TiO_2)	0.099
P	0.01-0.24	Cu	0.005-0.17		
K	3-9.07	Cr	0.04-0.15		

Table 1 **Typical mass composition of sinter dust from the third field of an ESP unit [1]**

indicated that substantial quantities of particles below 1mμ are emitted at the exit of ESP units, even when they comply with environmental regulations. *Figure 1A* shows an example of particle volume distribution at the exit of an ESP, as obtained from **[2]**, while in *Figure 1B* the corresponding normalised particle concentration is shown. In this figure, the numerical concentration of particles, N, is also divided by the total particle number N_{tot} as deduced from *Figure 1A*.

In terms of number, submicron (PM_1) and the ultrafine ($PM_{0.1}$) particles are by far the most abundant.

It is widely accepted that ESPs are mostly ineffective in reducing ultrafine particles **[3]** and the same bag filters are effective only under specific conditions of dust loading and pressure drops.

WET ELECTROSTATIC SCRUBBING (WES)

WES is an emerging technology aimed at advancing the performance of conventional water scrubbers by improving gas absorption rate and particle capture. These improvements derive from the use of charged droplets and, optionally, from the exposure of the gas to a low-power corona source. WES units were tested on diesel particles **[4]** and combustion particles **[5]** and the concept was used partially in a former industrial application by the Tri.Mer corp.**[5]** showed that a suitable WES removes >90% by number of submicron and ultrafine particles, reaching a mass removal efficiency higher than 95%. The corresponding water consumption was less than 1.2kg/Nm^3. The physics of particle removal in conventional scrubbing systems makes these performances unreliable and requires more than 20 times the amount of water used in a WES. Furthermore, the WES inherits all the features of wet scrubbers, including the low pressure drop. Boldrocchi and the University of Naples are now designing and prototyping a new generation of WESs for industrial applications.

MATHEMATICAL MODELLING

This paper reports results of a mathematical model, which calculates the particle collection efficiency of a WES for a model sinter plant exhaust. In this paper we are considering as a benchmark, the experimental set-up described in **[5]**. A model gas was considered and we varied liquid-to gas mass flow rate, L/G, and droplet electrostatic charge. Particle removal efficiency were calculated by the stochastic model reported by Carotenuto et al. **[6]** and the results are compared and discussed.

Methods In this paper we assume that the gas stream has the same properties of ambient air with 95% relative humidity. To mimic the main features of sinter plant exhausts, we considered the same particle size distribution shown in *Figure 1* and assume that the particles are either pure iron, silica or sodium chloride, chosen as an example alkali chloride.

The WES used as benchmark for calculations was a stainless steel cylinder of 40cm inner diameter and 3.5m height. The system geometry and the operational parameters were chosen according to **[5]**, although for intellectual property limitations, we model the corona source as a simple wire-and-tube unit of 500mm length and a wire of 0.5mm diameter operated at 15kV.

Moreover, we assumed that:

i) the gas flow rate is 150 Nm^3/h

ii) the water is sprayed according to the properties of the full-cone nozzle Lechler model 460-484 **[5]** which has a spray angle of 45 degrees

iii) the droplet size distribution followed the Rosin-Rammler model:

$$F(D) = 1 - \exp\left[-\left(\frac{D}{a}\right)^{b}\right] \tag{1}$$

where *F(D)* is the total fraction of drops with diameter smaller than *D*, and a and b are constants determined from the measurements. The parameters are a = 373.2±3.87 μm and b = 3.269±0.15. We assume that each droplet leaving the nozzle carries a uniform charge level q (in Coulomb), varying between 5 and 20% of its Rayleigh limit charge:

$$q_R = 2\pi\sqrt{2\varepsilon\gamma_W D^3} \tag{2}$$

where $q\__R$ is the is the Rayleigh limit charge (in Coulomb), ε is air permittivity and γw is the droplet surface tension.

The particle capture model follows the approach of that presented by Carotenuto et al., **[6]**. Assuming that the radial distribution of any variable in the scrubber is uniform, the particle population balance, in a given scrubber section of thickness *dz*, is:

$$Gdn = -r(z, d_p) \tag{3}$$

where *G* is the volumetric gas flow rate, *n* is the numerical concentration of particle of size d_p per unit volume, and $r(z,d_p)$ is their scavenging rate. In case of uniform size of sprayed droplets, the value of $r(z,d_p)$ is:

$$r(z, d_p) = U_t(D(z)) \cdot E(D(z), d_p) \cdot \frac{\pi}{4} \cdot \left[D(z) + d_p\right]^2 \cdot n(d_p) \cdot N(z) \cdot Sdz \tag{4}$$

where $E(D(z), d_p)$ is the total collision efficiency, *N(z)* is the numerical droplet concentration per unit volume and *S* is the cross-section of the scrubber.

Substitution of eq. (4) in eq. (3) and integration, by separation of variables over the scrubber length, *L*, gives the numerical concentration of the particles of size d_p at

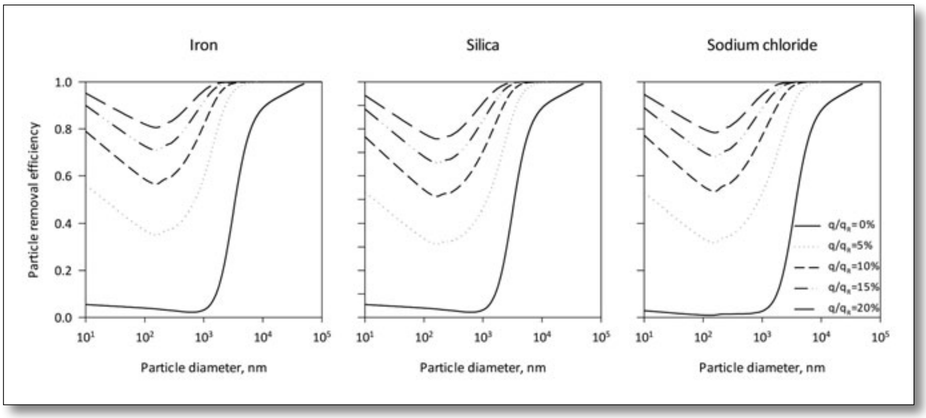

Fig 2 **Particle removal efficiency as a function of particle diameter and parametric with the ratio between droplet charge and corresponding Rayleigh charge, q/qR, for a liquid-to-gas ratio of L/G=0.5 kg/kg**

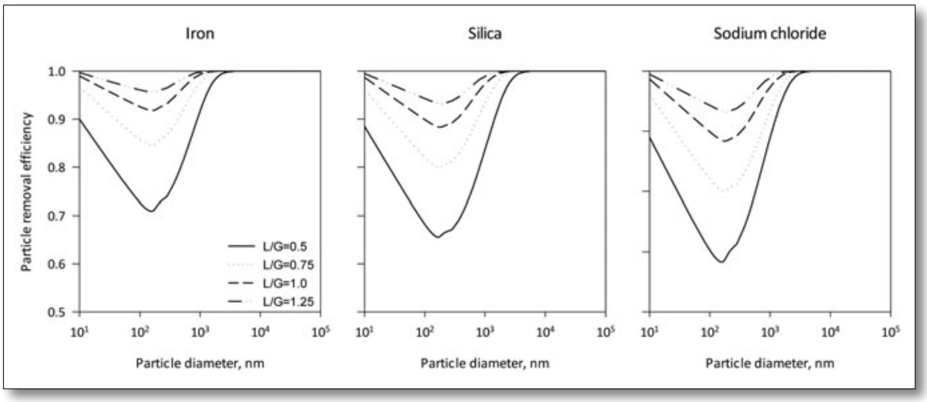

Fig 3 **Particle removal efficiency as a function of particle diameter parametric with the liquid-to-gas ratio, L/G, for a value of the ratio between droplet charge and corresponding Rayleigh charge, q/qR=15%**

the scrubber exit, n_L:

$$\ln\left(\frac{n_L}{n_0}\right) = -\int_0^L \frac{U_t(D(z))}{U} \cdot E\left(D(z), d_p\right) \cdot \frac{\pi}{4} \cdot \left[D(z) + d_p\right]^2 \cdot N(z) \cdot dz \tag{5}$$

In this equation, n_o is the concentration of particle with size d_p entering the scrubber.

When a given droplet size distribution, $\Psi(D_0)$ is produced by the nozzle, as in real conditions, allowances must be made to take into account the concentration of each droplet size in a given section at position z. In this case, eq. (5) becomes:

$$\ln\left(\frac{n_L}{n_0}\right) = -\int_0^\infty \int_0^L \frac{U_t(D(z))}{U} \cdot E\left(D(z), d_p\right) \cdot \frac{\pi}{4} \cdot \left[D(z) + d_p\right]^2 \cdot N(z) \cdot dz \cdot \Psi(D_0) \cdot dD_0 \tag{6}$$

Finally, the numerical particle collection efficiency, $\eta(d_p)$ is calculated as:

$$\eta(d_p) = 1 - \frac{n_L}{n_0} \tag{7}$$

The model calculation includes a simplified description of droplet hydrodynamics of droplets evaporation/condensation phenomena, and the estimation of droplet losses on the scrubber walls as shown in previous work [5-8]. Preliminary estimation indicates that Coulomb fission of droplets is negligible.

RESULTS AND DISCUSSION

Figure 2 shows the effect of droplet charge on the capture of particles for the three materials at the value of the liquid-to-gas ratio, L/G = 0.5kg/kg. Even in this case, there is a high removal efficiency, which is >70% for droplet charging over 15%. Physical properties of the particles have slight effects on $\eta(d_p)$.

Figure 2 shows that for uncharged scrubbing, particle removal below 2,000nm is very low at the investigated L/G ratios. This is typical of particles in the Greenfield gap (100-2,000nm), which have low inertia and are affected by limited Brownian motion. By imposing the electric forces through charging of droplets and particles, the removal efficiency strongly increases, giving rise to a sharp minimum for particle diameters close to 100nm.

Figure 3 resumes the simulation results on the effect of water flow rate on particle capture. We are considering, ▷

Iron				
	q/ qR=5%	**q/ qR=10%**	**q/ qR=15%**	**q/ qR=20%**
L/G=0.5	56	79	90	95
L/G=0.75	71	90	97	99
L/G=1	81	96	99	100
L/G=1.25	87	98	100	100
Silica				
	q/ qR=5%	**q/ qR=10%**	**q/ qR=15%**	**q/ qR=20%**
L/G=0.5	53	77	89	94
L/G=0.75	68	89	96	99
L/G=1	78	95	99	100
L/G=1.25	85	97	100	100
Sodium chloride				
	q/ qR=5%	**q/ qR=10%**	**q/ qR=15%**	**q/ qR=20%**
L/G=0.5	53	77	89	95
L/G=0.75	68	89	96	99
L/G=1	78	95	99	100
L/G=1.25	85	98	100	100

Table 2 **Total number removal efficiency as a function of the ratio between droplet charge and corresponding Rayleigh charge, q/qR and the liquid-to-gas ratio of L/G, for the three materials**

as a benchmark, q/qR=15%. By increasing L/G up to 1.25kg/kg, $\eta(d_p)$ becomes higher than 90% for all particle materials and diameters.

Table 2 summarises the values of the total removal efficiency, tot, showing that the WES system can achieve η_{tot}>90% for all the three model constituents of sinter plant dust.

CONCLUSIONS

This paper presents the results of a mathematical model of a WES to predict the abatement of three different possible constituents of sinter plant emissions. The model results show that wet electrostatic scrubbing operated with a liquid-to-gas ratio of 0.75kg/kg (with drops charged at 10% of their Rayleigh limit) can remove all these particles with number efficiencies higher than 89%. The corresponding mass removal efficiencies are even higher. This result is comparable with existing best available technology (BATs), proving that this process can be a reliable alternative or a useful update to ESPs and bag filters and encouraging the development of new tests for iron and steel industry applications. **MS**

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